NASA Contractor Report 3117

Bumblebee Program - Aerodynamic Data

Part IV - Wing Loads at Mach Numbers 1.5 and 2.0

G. A. Barnes and L. L. Cronvich

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CONTENTS

SUMMARY

This report provides individual wing panel aerodynamic characteristics (specifically, normal force coefficient and center of pressure location) for rectangular wings of three different aspect ratios (0.25, 0.75 and 1.00 each panel). Results are presented in the form of data plots at Mach numbers of 1.5 and 2.0 for angles of attack from 0 to 23 degrees and, for the most part, at aerodynamic roll orientations of 0 and 45 degrees. The wing with an aspect ratio of 1.00 is the same wing used in the flow field studies which are discussed in Part II of this report series.

INTRODUCTION

Knowledge of individual missile wing panel loads as a function of Mach number, angle of attack, and aerodynamic roll orientation is required by the theoretician in the development and verification of computational approaches to the definition of various aerodynamic flow phenomena. For example, wing loads, preferably experimental values, are required to formulate the effect of the wing downwash field on the lift of tail surfaces and on a certain portion of the missile body downstream of the wing trailing edges.

The purpose of this Part IV report is to provide wing normal force coefficients and center of pressure locations in the form of plots of experimental data for wing panels of aspect ratios 0.25, 0.75, and 1.0 (each panel) at Mach numbers of 1.5 and 2.0 for angles of attack to 23 degrees. These panels were chosen as a representative variation in one generic set of wing planform designs.

This report is the fourth in a four-part series published under the general title:

"Bumblebee Program - Aerodynamic Data".

Part I discusses the purpose of this effort and how the information in the other three reports is related.

Part II presents data at M = 2.0 which define the flow field around a concial-nosed, cylindrical missile body in a crossflow plane corresponding to a likely tail location.

Part III presents the Mach number effect (M = 1.5 and 2.0) on pressure fields only since complete flow field data are available in the Bumblebee Program at M = 2.0 only. This comparison is at a missile body station where a wing leading edge is likely to be located.

NOMENCLATURE

C_N, $C_{N,p}$, $C_{N,w}$	single panel normal force coefficient perpendicular to hub centerline in a plane perpendicular to body centerline	$= \frac{N_w}{qS_w}$
N_w	single panel normal force	(pounds)
S_w	area of one exposed wing panel	(sq.in.)
q	free stream dynamic pressure	(psi)
x_{cp}, $x_{cp,w}$	wing panel chordwise center of pressure from root leading edge	(% chord)
y_{cp}	wing panel spanwise center of pressure from root chord	(% single panel span)
$y_{cp,w}$	wing panel spanwise center of pressure from body centerline*	(% panel span from body centerline)
α, α_c	angle of attack corrected for support deflection in vertical plane of the tunnel referred to tunnel centerline; nose up is positive	(degrees)
ϕ	body roll attitude; positive is clockwise looking upstream (ϕ = 0 when wings are horizontal and vertical)	(degrees)

The following coefficients are included in several data plots but will not be discussed in this report.

$C_{h,w}$	individual wing panel hinge moment coefficient
C_ℓ	rolling-moment coefficient with respect to body longitudinal axis from Stability and Control tests

*Applies for B_5W_4 data at M = 2.0 only. The following expression can be used to convert to y_{cp} (percent of single panel span).

$$y_{cp} = \frac{y_{cp,w} - 25.5}{0.745}$$

$C_{\ell,w}$ rolling-moment coefficient with respect to body longitudinal axis, computed from instrumented wing panel data of wing hinge-moment tests.

For following definitions see Model Configuration Sketch (Fig. 1). Left and Right denote the number 4 and 2 panels, respectively.

i_w wing deflection (incidence) on panels 2 and 4 with respect to body axis; leading edge up is positive (degrees)

i'_w wing deflection (incidence) on panels 1 and 3 with respect to body axis; leading edge right is positive (degrees)

i_w/i'_w = 0/-, for example, denotes a planar configuration with panels 1 and 3 removed.

DISCUSSION

This Part IV report provides inidvidual wing panel aerodynamic characteristics (specifically normal force coefficient and center of pressure location) for rectangular wing panels with aspect ratios of 0.25, 0.75, and 1.0 (each panel) at Mach numbers of 1.5 and 2.0 for angles of attack to 23 degrees. The location of the wing leading edge is at the same mid-body station where the pressure fields at M = 1.5 and 2.0 are defined in Part III. Also, one of the wings (W_4) included herein is the same as the one used in the complete flow field study (Part II) to determine the effect of wing downwash at a body station corresponding to a likely tail location. The location of these survey stations relative to the wing location is given by the model sketch in Fig. 1.

Source of Data

The normal force coefficients, and the chordwise and spanwise center of pressure locations are given in Appendix A in the form of data plots. These plots were reproduced from several reports of wind tunnel tests conducted as part of the overall Bumblebee Generalized Missile Study (GMS).* Some portions of these plots have been blanked out and other information added for clarity.

Sketchs of the wing planform are given in Fig. 1.

General Comments

Some notes concerning the plotted data of Appendix A follow.

- Actual wind tunnel data were plotted. No zero shifts were made.
- Data for wing deflections of 10° and 20° are exemplified for W_4 at M = 2.0 only.
- Center-of-pressure data are questionable at low α due to hinge moment balance accuracy.

* The Ordnance Aerophysics Laboratory (OAL) wind tunnel tests from which the wing panel data were obtained are: OAL Reports 289-4, -11, -12, -25, -26, "Investigation of Induced Roll and Longitudinal Stability Characteristics of a Generalized Missile Model at Mach Numbers of 1.5 and 2.0," 25 April, 5 and 6 August 1955.

- Spanwise center of pressure for the low aspect ratio wing (W_{30}) is erratic at all values of α and M, probably because of the large percentage of the wing area that is immersed in the non-uniform flow field near the body surface.
- The planar configuration (two panels) is obtained by removing the number 1 and 3 panels (see Fig. 1).
- It should be noted that data for the B_5W_4 configurations at M = 2.0 were plotted in a different format compared to the rest of the data. Included in these plots are wing hinge moment coefficient and rolling moment coefficient. Neither of these coefficients will be considered in this Wing Loads report (see Nomenclature).

Examples

The data plotted in Figs. 2 and 3 exemplify how the data of Appendix A can be used.

Shown in Fig. 2 is the Mach number effect on the normal force coefficient for the largest of the wing panels (W_4) at a zero degree roll angle (see Fig. 1). It should be remembered that the reference area for $C_{N,p}$ is the single panel planform area.

The effect of wing panel aspect ratio (or panel span in this case) is shown in Fig. 3 for M = 2.0.

Another comparison that could be made but has not been shown is a planar versus a cruciform wing (W_4) at both Mach numbers which would give wing-wing interference effects.

The effect of aerodynamic roll orientation on wing panel characteristics is also included in the data plots of Appendix A.

CONCLUDING REMARKS

In summary, this report provides data plots that define the normal force coefficients and center of pressure locations for rectangular missile wings of three different aspect ratios at Mach numbers of 1.5 and 2.0. These plots will enable one to verify the theoretical methods over a range of aspect ratios which are commonly used in missile applications.

Generalized Missile Study

Wind Tunnel Models

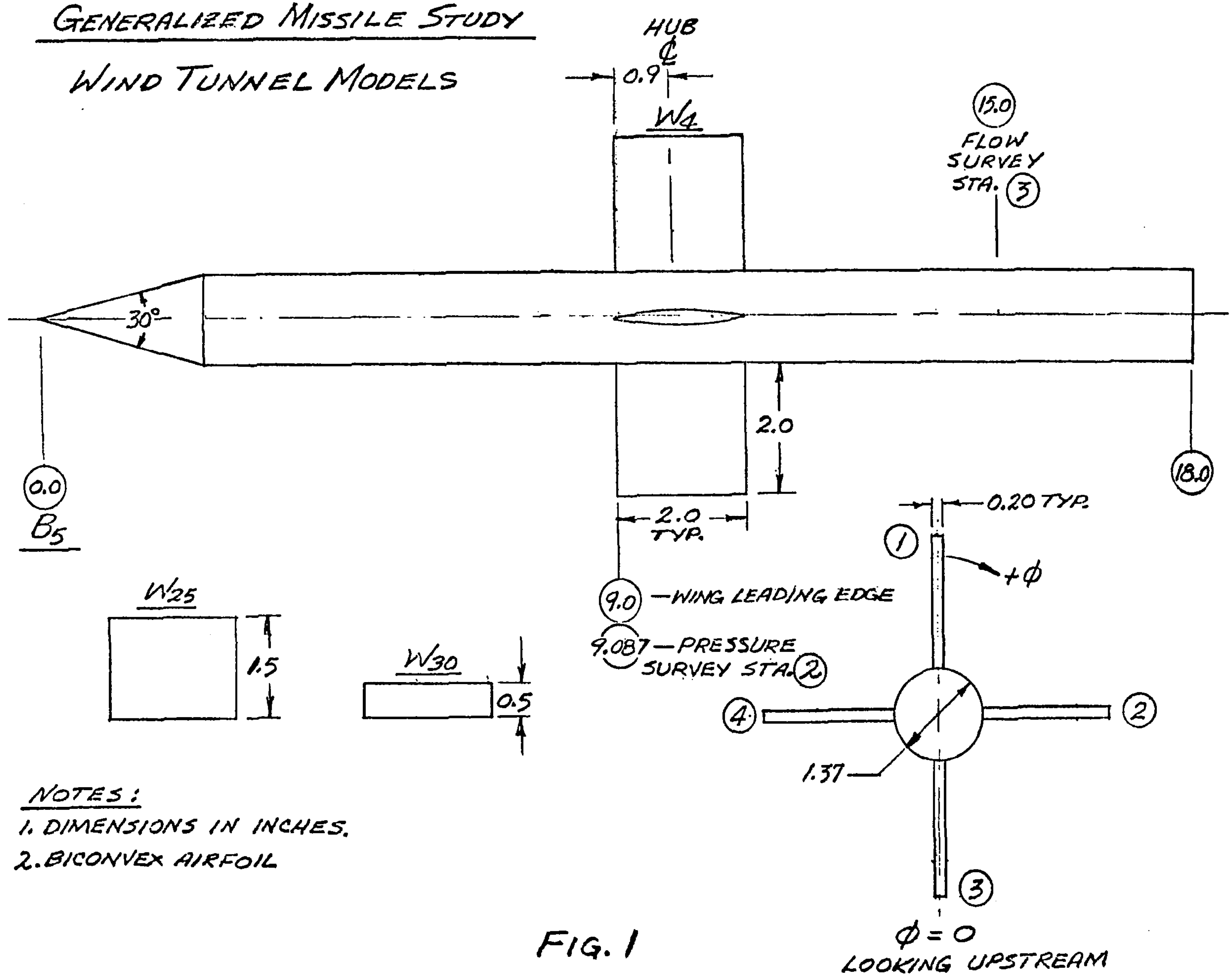


FIG. 1

NOTES:
1. DIMENSIONS IN INCHES.
2. BICONVEX AIRFOIL

WING NORMAL FORCE COEFFICIENT

$B_5 W_4$

$\phi = 0$, $i_w/i_x = \%$

M	TEST
1.5	0AL289-11
2.0	0AL289-4

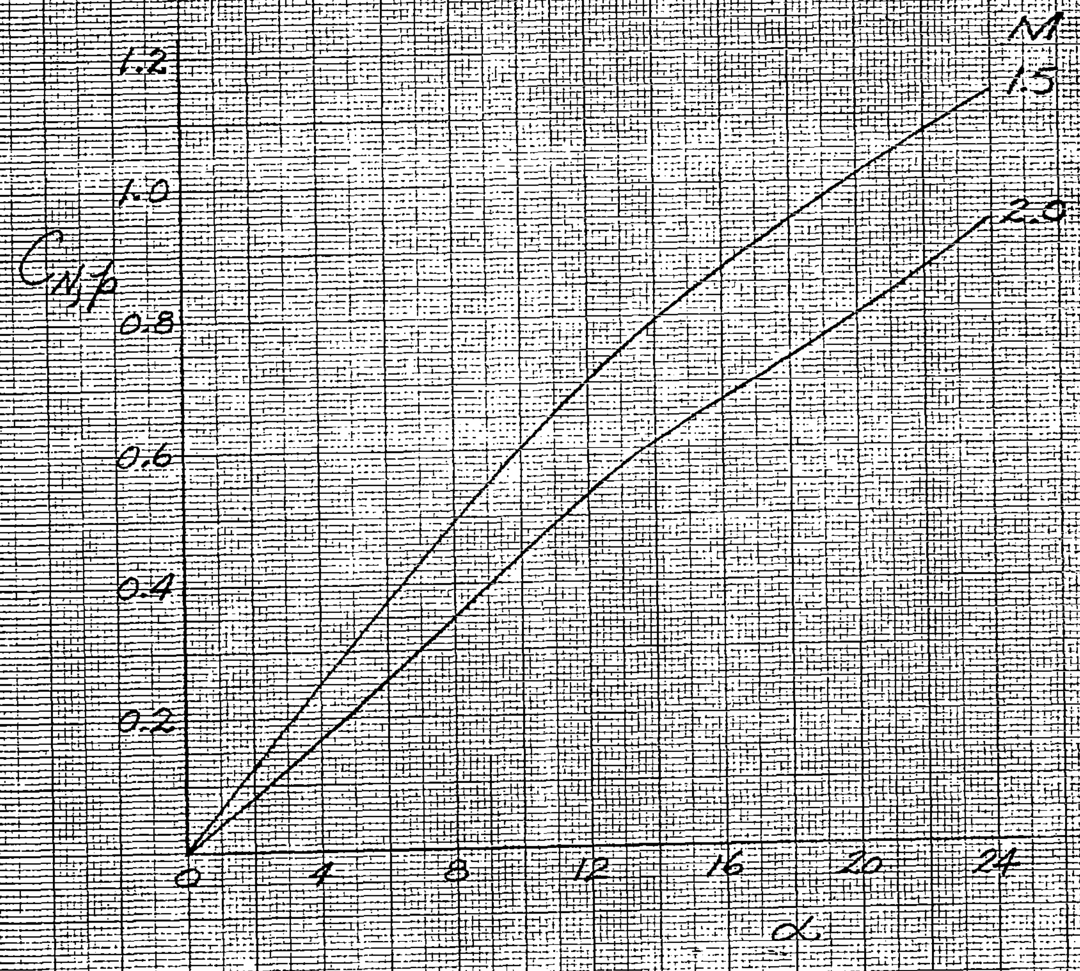


FIG. 2

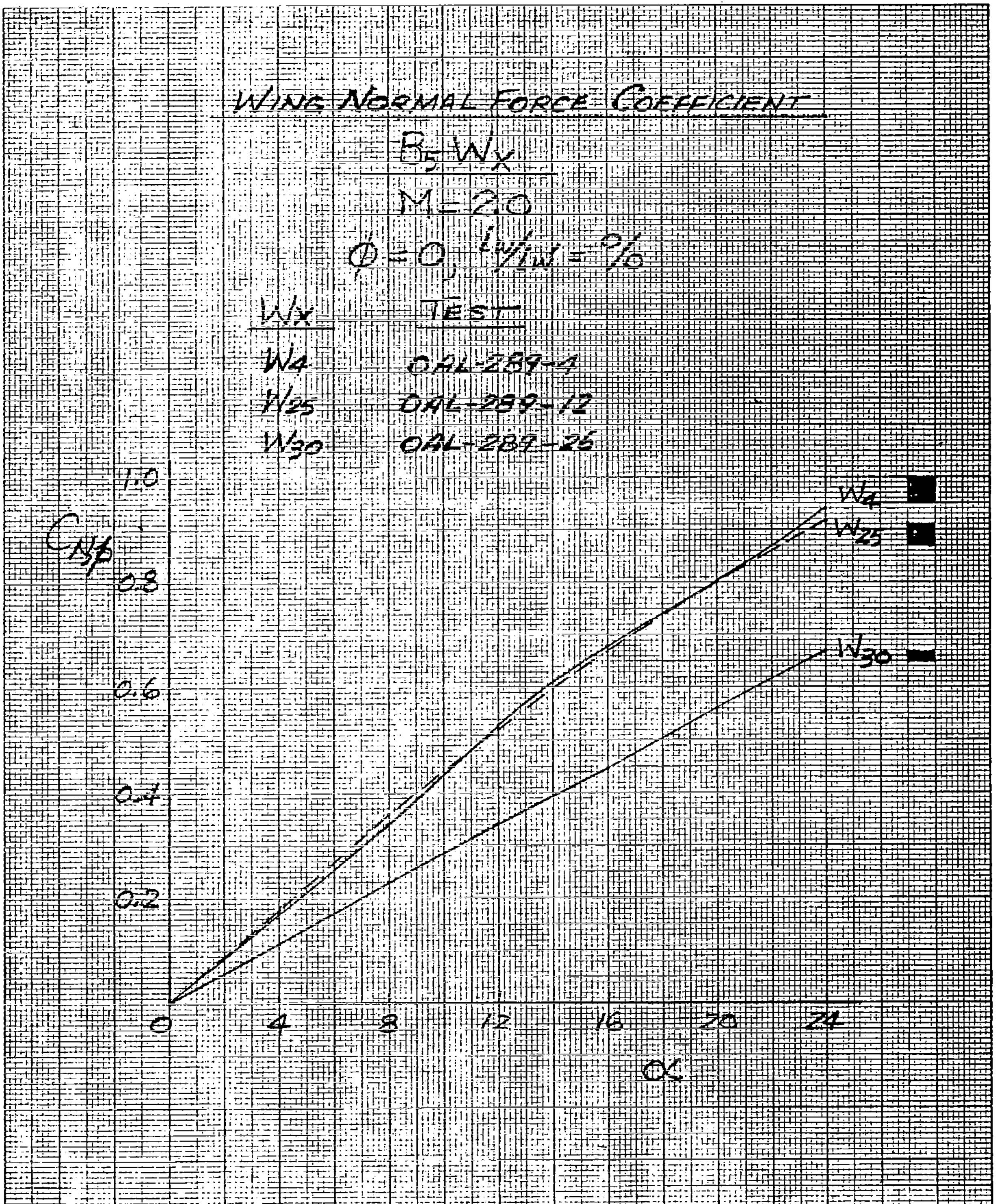

WING NORMAL FORCE COEFFICIENT
B5 Wx
M-20
Φ=0, iW/iW = 0/0
Wx TEST
W4 OAL-289-4
W25 OAL-289-12
W30 OAL-289-25
CN/P
1.0
0.8
0.6
0.4
0.2
0
4
8
12
16
20
24
α
W4
W25
W30

FIG. 3

APPENDIX - A

PLOTS OF WING NORMAL FORCE COEFFICIENT AND CENTER OF PRESSURE

Data plots are presented in the following order:

M = 1.5

$C_{N,p}$; x_{cp}; y_{cp} vs. α - Left and Right Panels

B_5W_4 - planar - ϕ = 0, 45
B_5W_4 - planar - ϕ = 0, 15, 30, 45
B_5W_4 - cruciform - ϕ = 0, 45
B_5W_4 - cruciform - ϕ = 0, 15, 30, 45
B_5W_{25} - cruciform - ϕ = 0, 45
B_5W_{30} - cruciform - ϕ = 0, 45

M = 2.0

$C_{N,w}$; $x_{cp,w}$; $y_{cp,w}$ vs. α_c - Left and Right Panels

B_5W_4 - planar - ϕ = 0, 45

B_5W_4 - cruciform - ϕ = 0, 45

(Effect of wing deflection is shown on above B_5W_4 plots.)

$C_{N,w}$; $x_{cp,w}$ vs. α_c - Left and Right Panels

B_5W_4 - planar and cruciform - ϕ = 15, 30, -60, -85

$C_{N,p}$; x_{cp}; y_{cp} vs. α - Left and Right Panels

B_5W_{25} - cruciform - ϕ = 0,45
B_5W_{30} - cruciform - ϕ = 0, 45

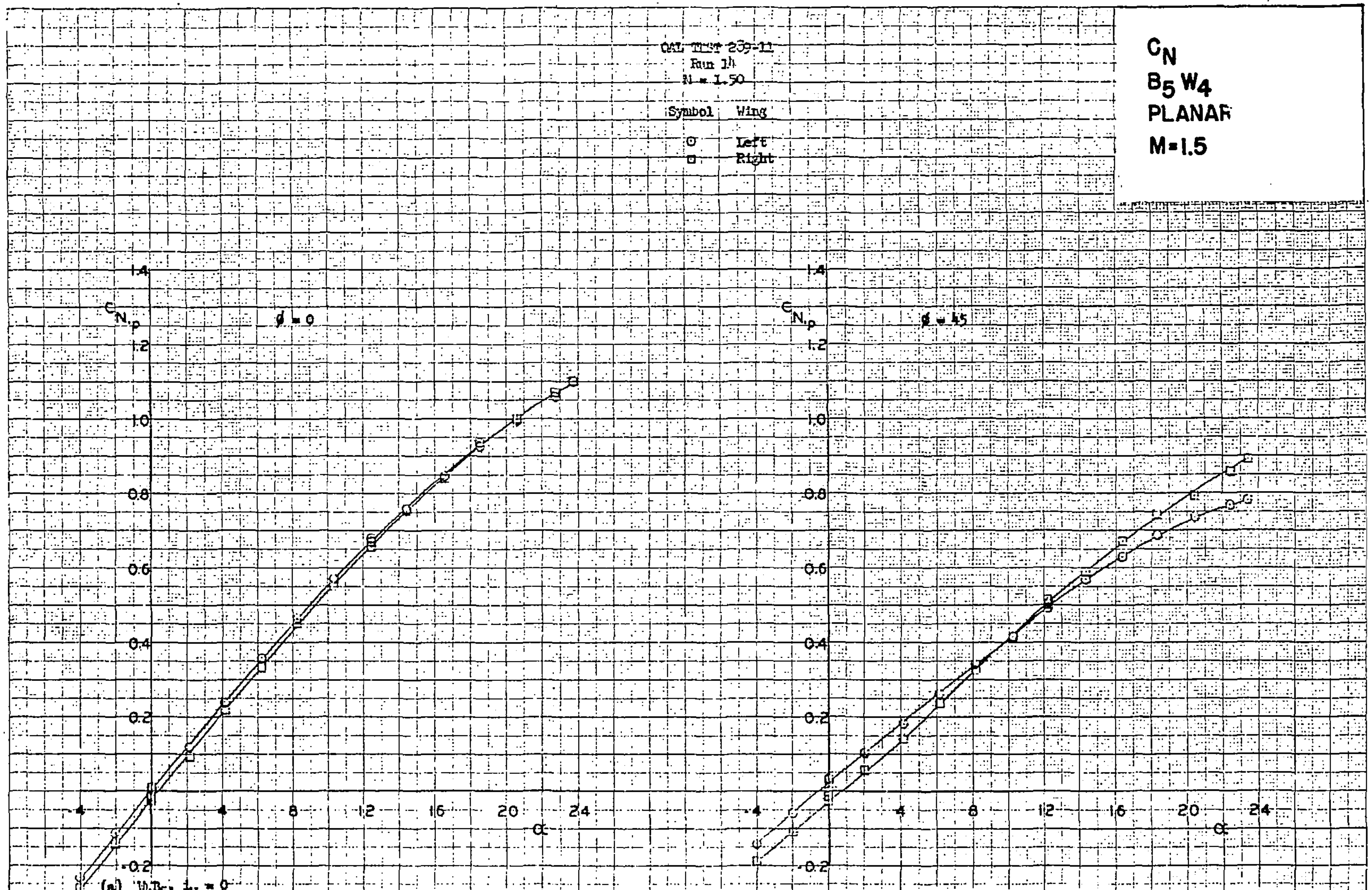
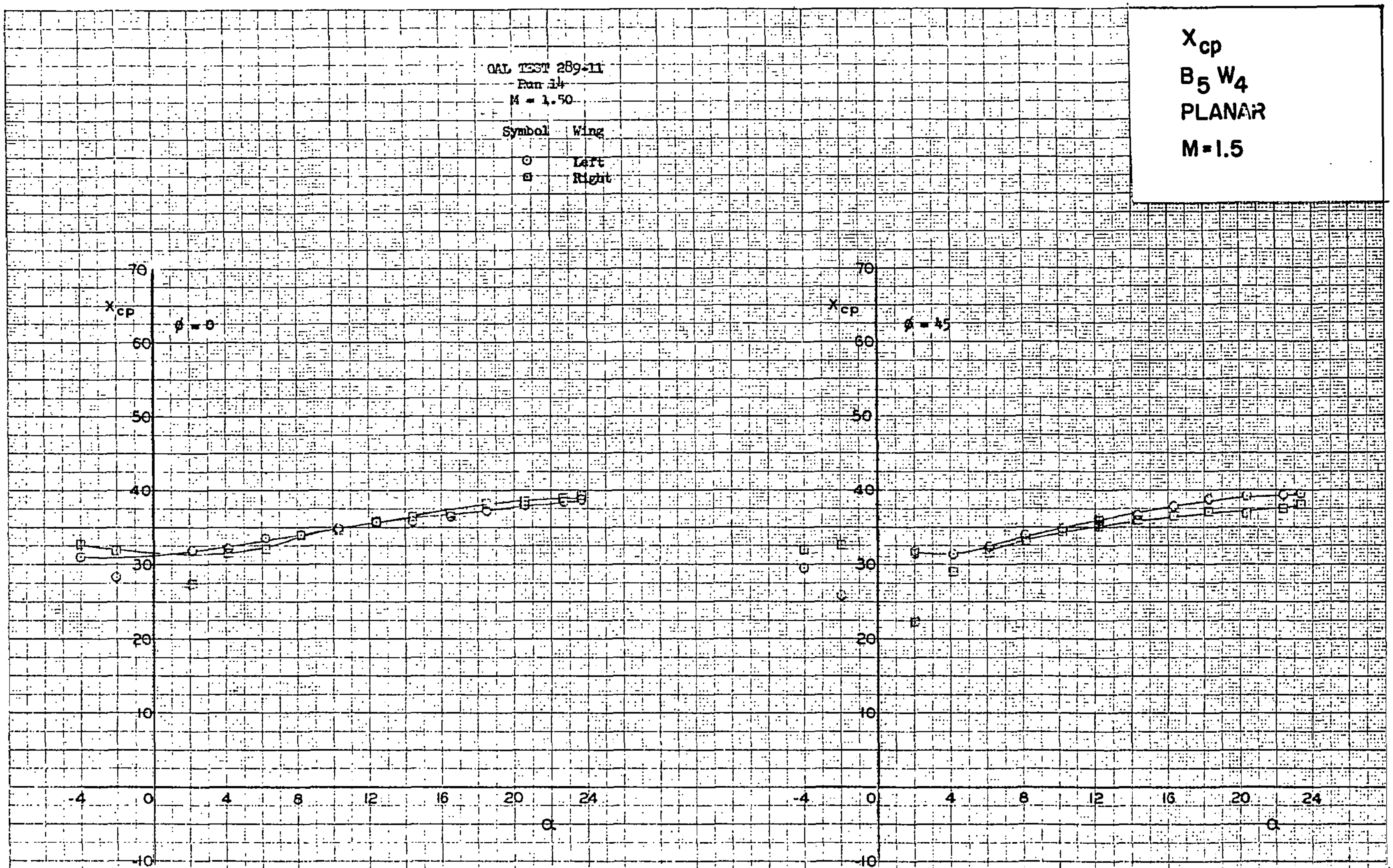
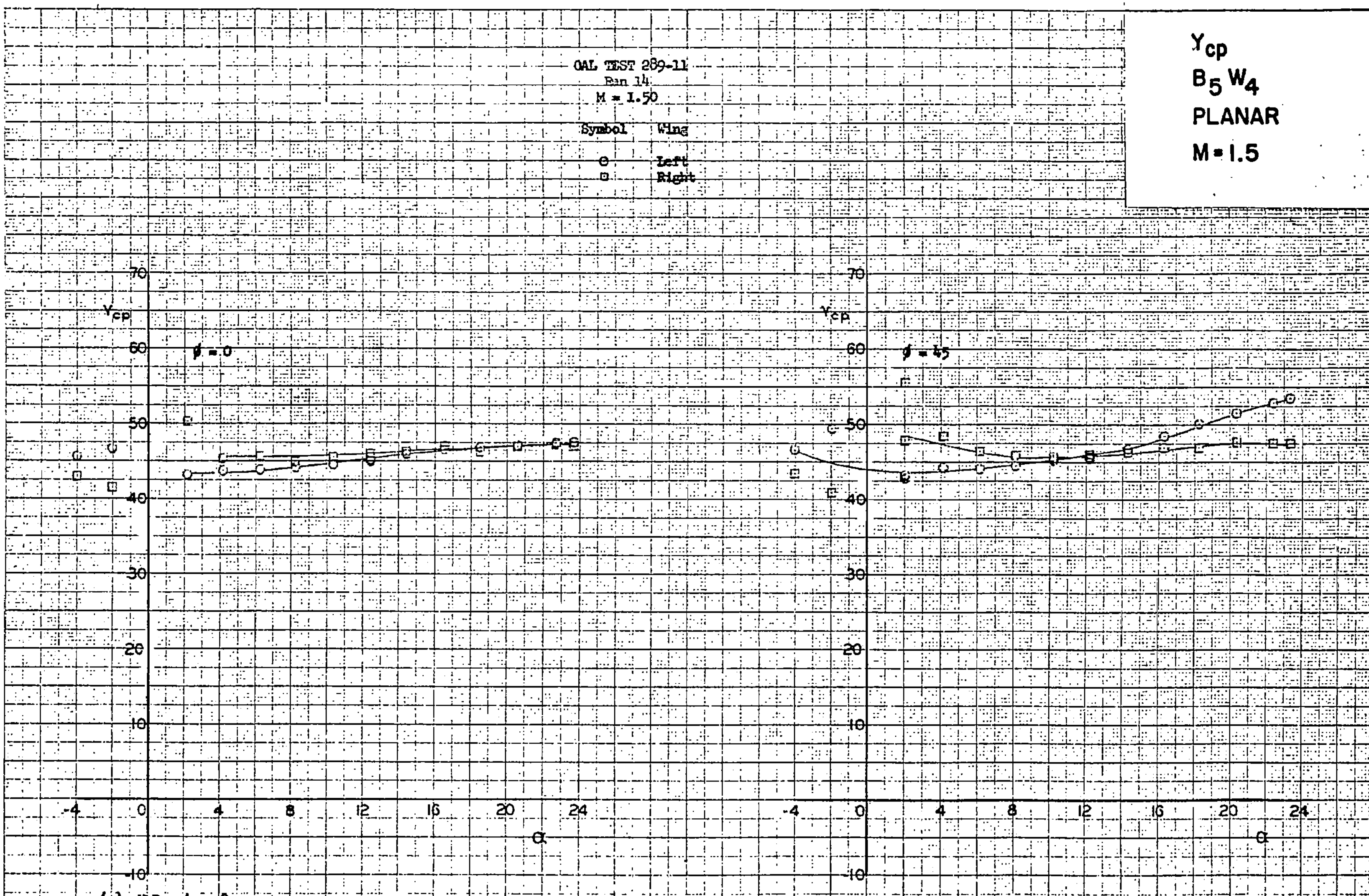


FIGURE 26 LEFT AND RIGHT WING PANEL NORMAL-FORCE COEFFICIENTS AS A FUNCTION OF ANGLE OF ATTACK FOR PLANAR AND CRUCIFORM WING-BODY CONFIGURATIONS WITH ZERO INCIDENCE AND WITH INCREASED FOREBODY LENGTH SHOWING THE EFFECT OF WING PLANFORM AT MACH NUMBER 1.50 (ϕ = 0 and 45)



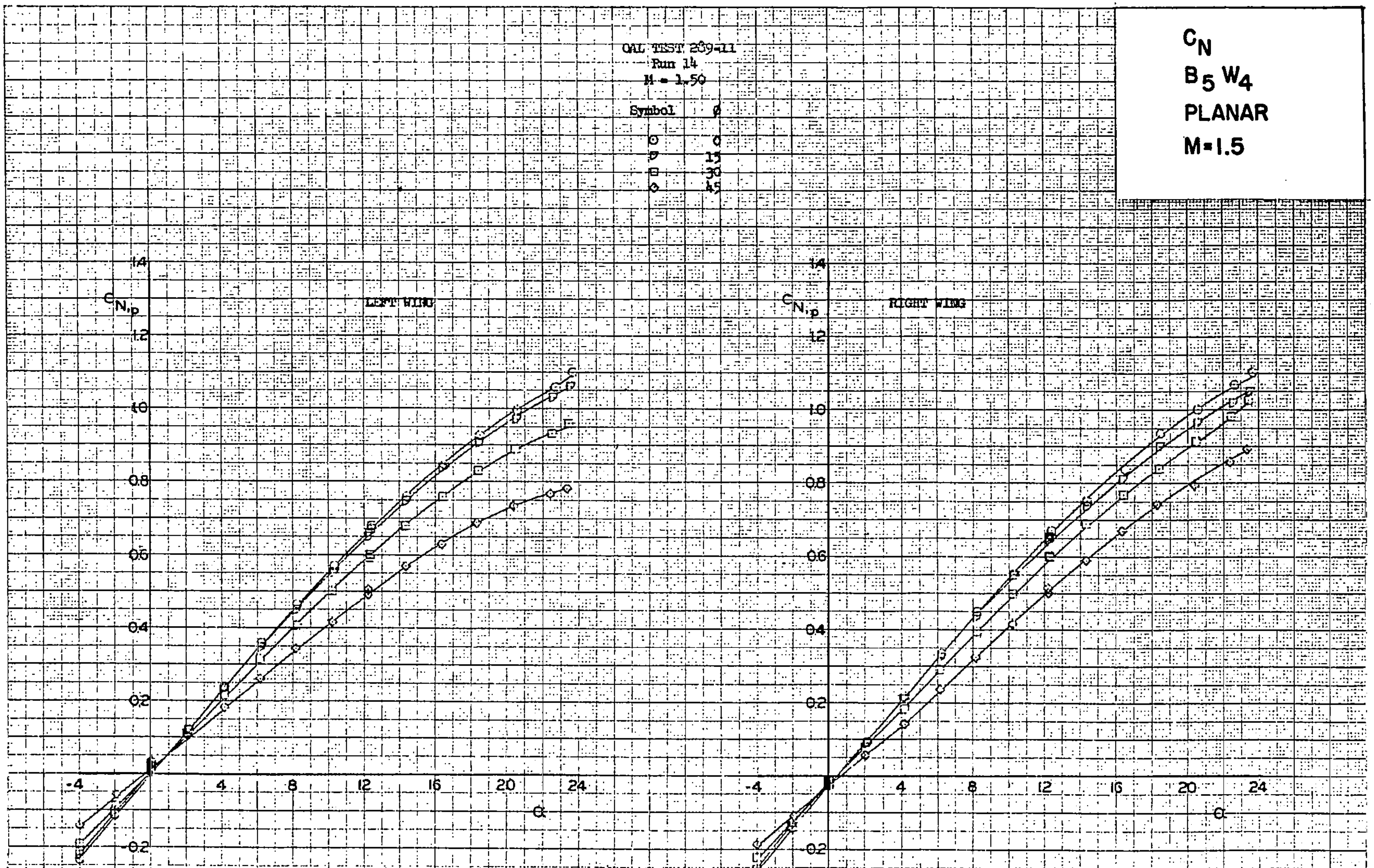
(a) W_4B_5, $i_W = 0$

FIGURE 30 LEFT AND RIGHT WING PANEL CHORDWISE CENTERS OF PRESSURE AS A FUNCTION OF ANGLE OF ATTACK FOR PLANAR AND CRUCIFORM WING-BODY CONFIGURATIONS WITH ZERO INCIDENCE AND WITH INCREASED FOREBODY LENGTH SHOWING THE EFFECT OF WING PLANFORM AT MACH NUMBER 1.50 (ϕ = 0 AND 45)



(a) W_4B_5, $i_w = 0$

FIGURE 29 LEFT AND RIGHT WING PANEL SPANWISE CENTERS OF PRESSURE AS A FUNCTION OF ANGLE OF ATTACK FOR PLANAR AND CRUCIFORM WING-BODY CONFIGURATIONS WITH ZERO INCIDENCE AND WITH INCREASED FOREBODY LENGTH SHOWING THE EFFECT OF WING PLANFORM AT MACH NUMBER 1.50 (ϕ = 0 AND 45)



(a) C_{Np} vs. α for W_4B_5, i_W = 0 (ø = 0 thru 45)

FIGURE 24 AERODYNAMIC CHARACTERISTICS OF THE WING PANELS ON A PLANAR WING-BODY CONFIGURATION (W_4B_5) WITH ZERO WING INCIDENCE AND WITH INCREASED FOREBODY LENGTH AT MACH NUMBER 1.50

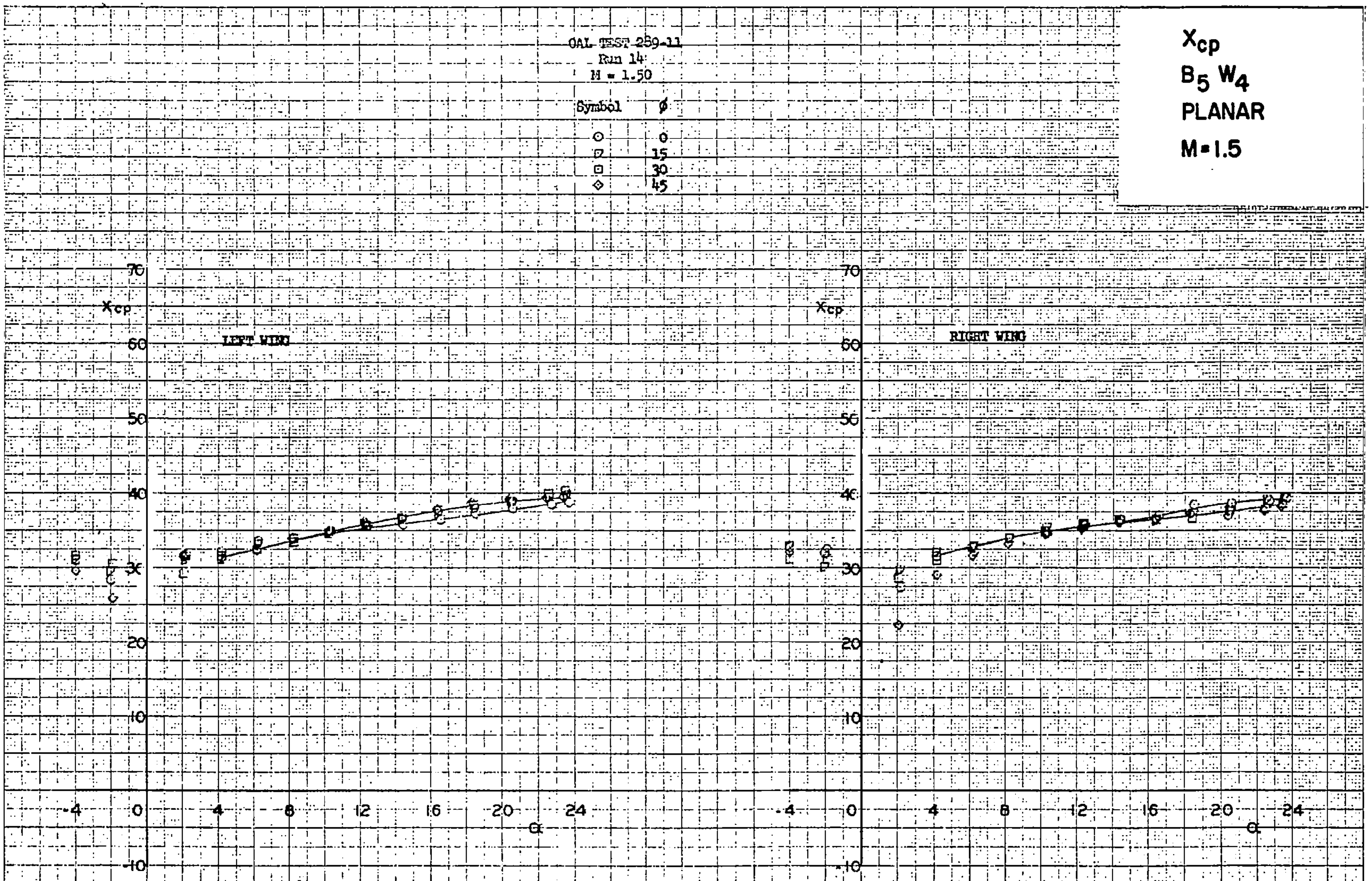
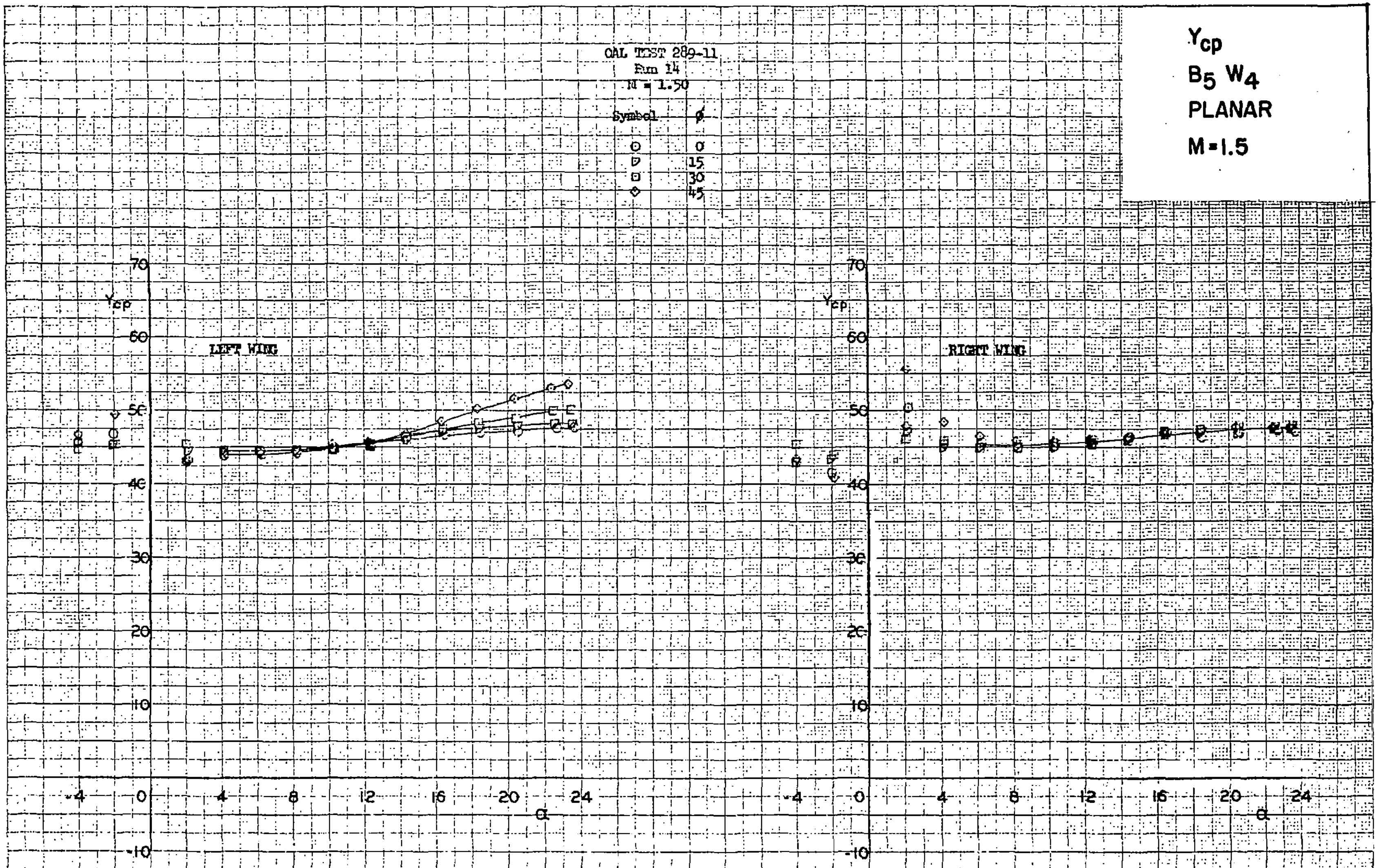
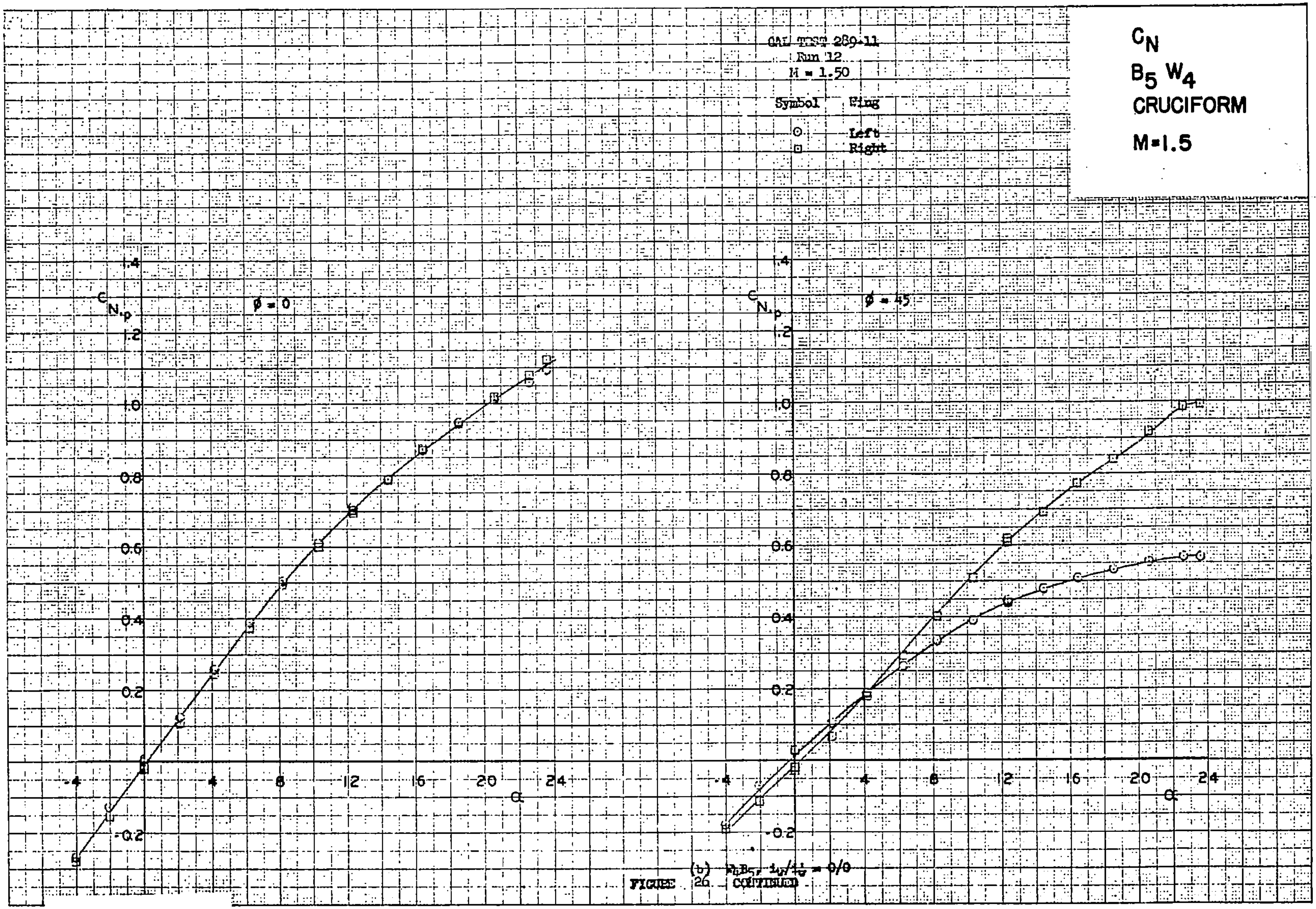


FIGURE 24 (1) X_{cp} vs. α for W_4B_5, $i_w = 0$ (ø = 0 thru 45) CONTINUED



(g) Y_{cp} vs. α for W_4B_5, $i_w = 0$ ($\phi = 0$ thru 45)
FIGURE 24 CONTINUED



(b) W_4B_5, $i_L/i_R = 0/0$

FIGURE 26 CONTINUED

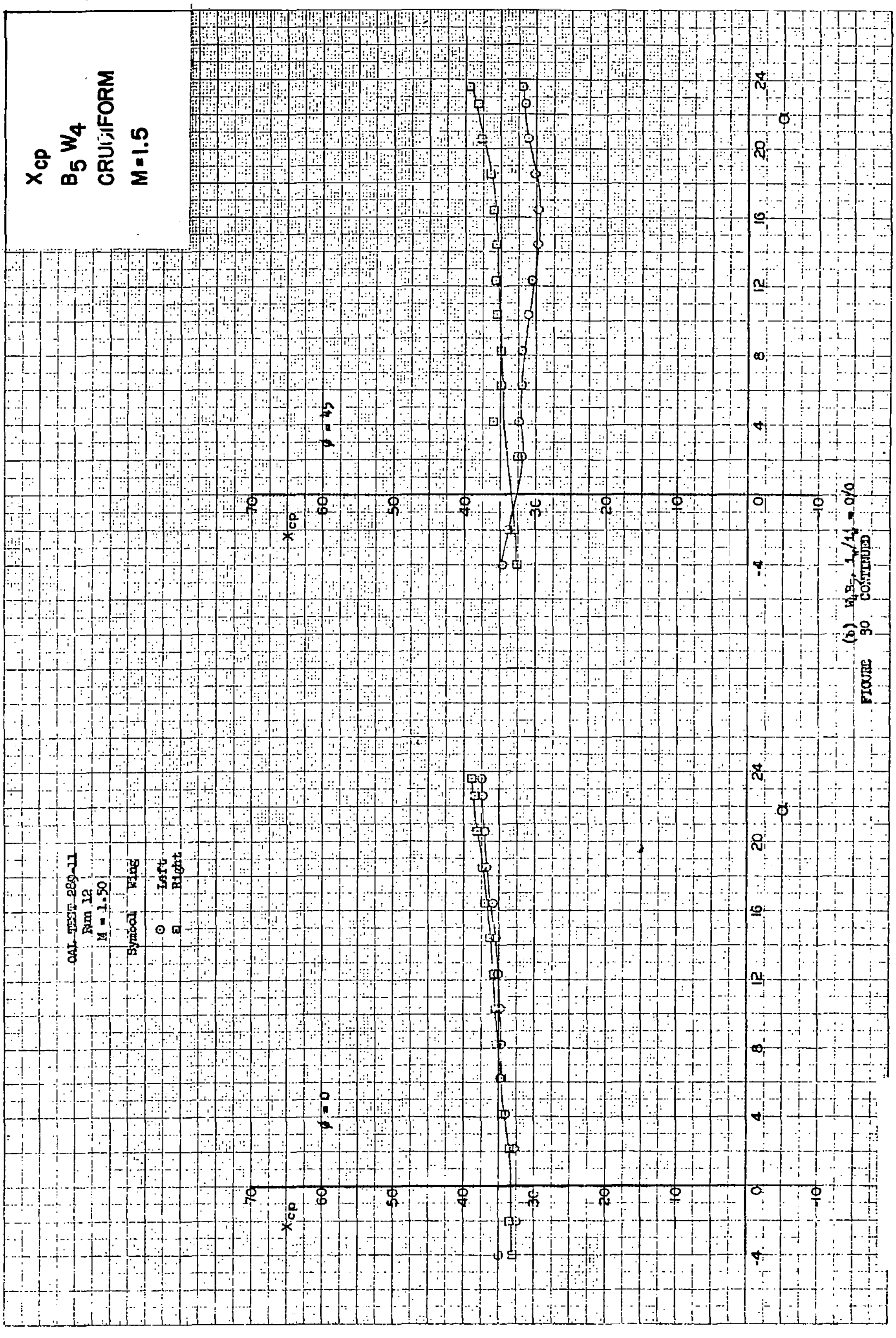
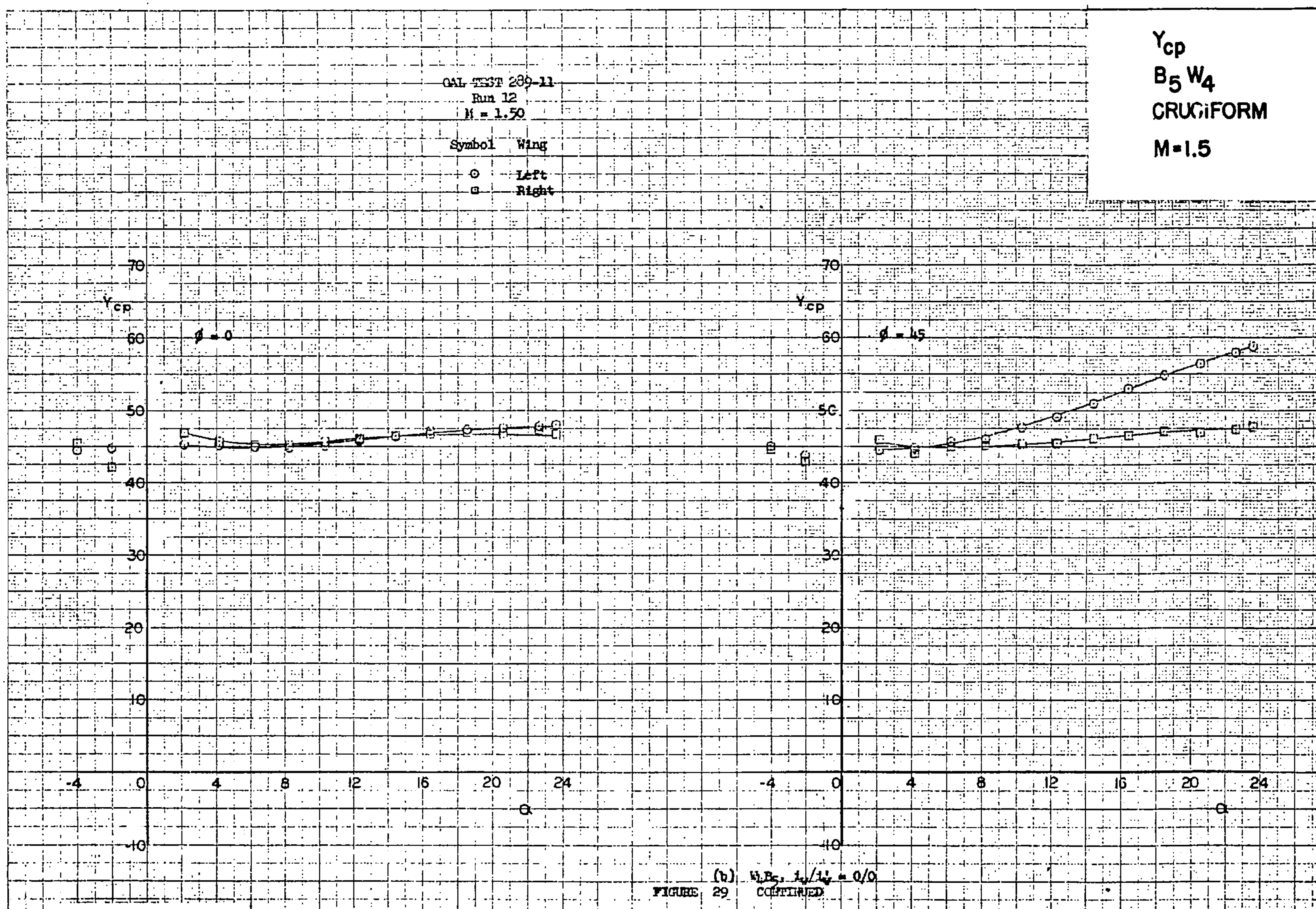
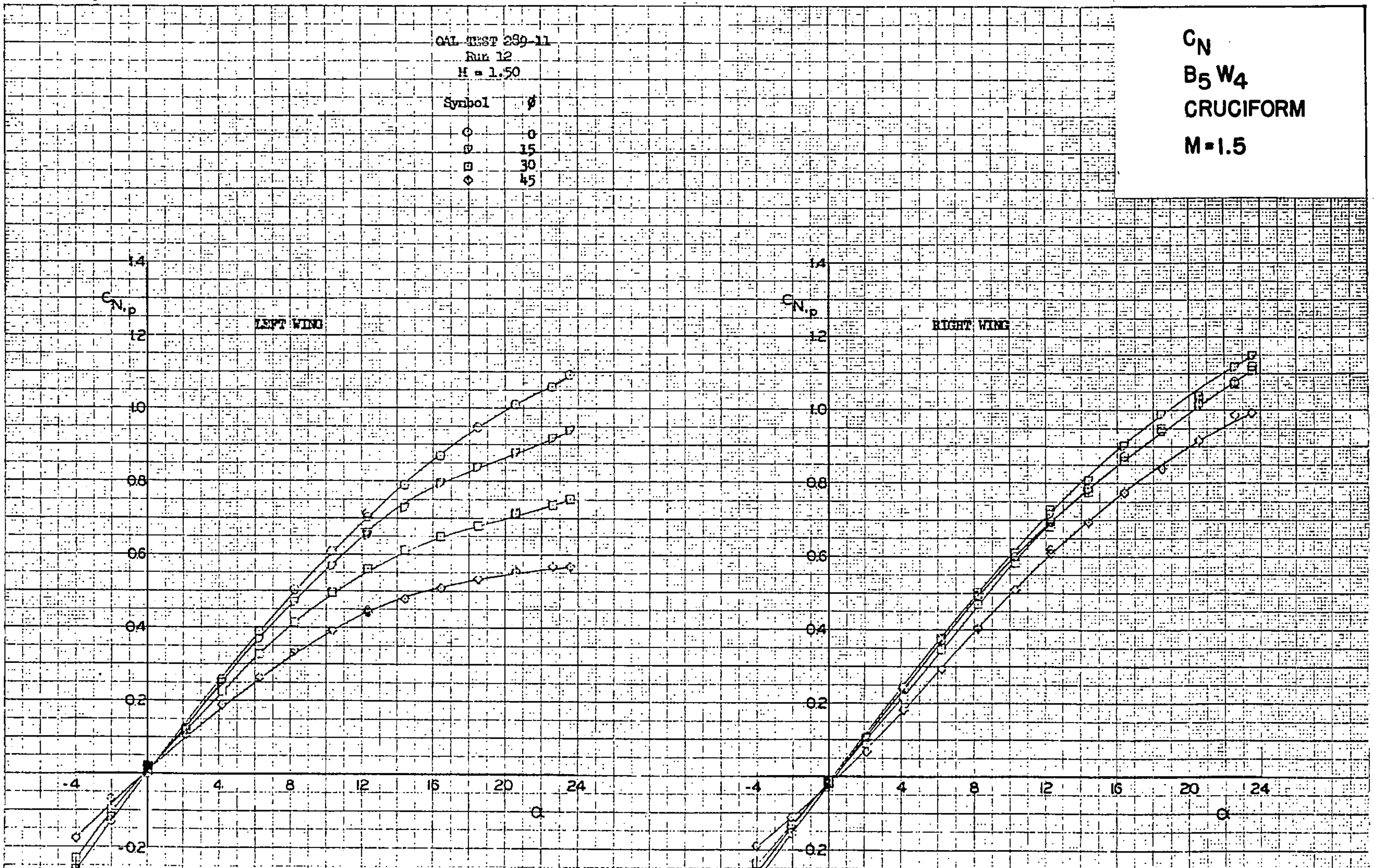


FIGURE 30 (b) W_4B_5, l_w/l_4 = 0/0 CONTINUED

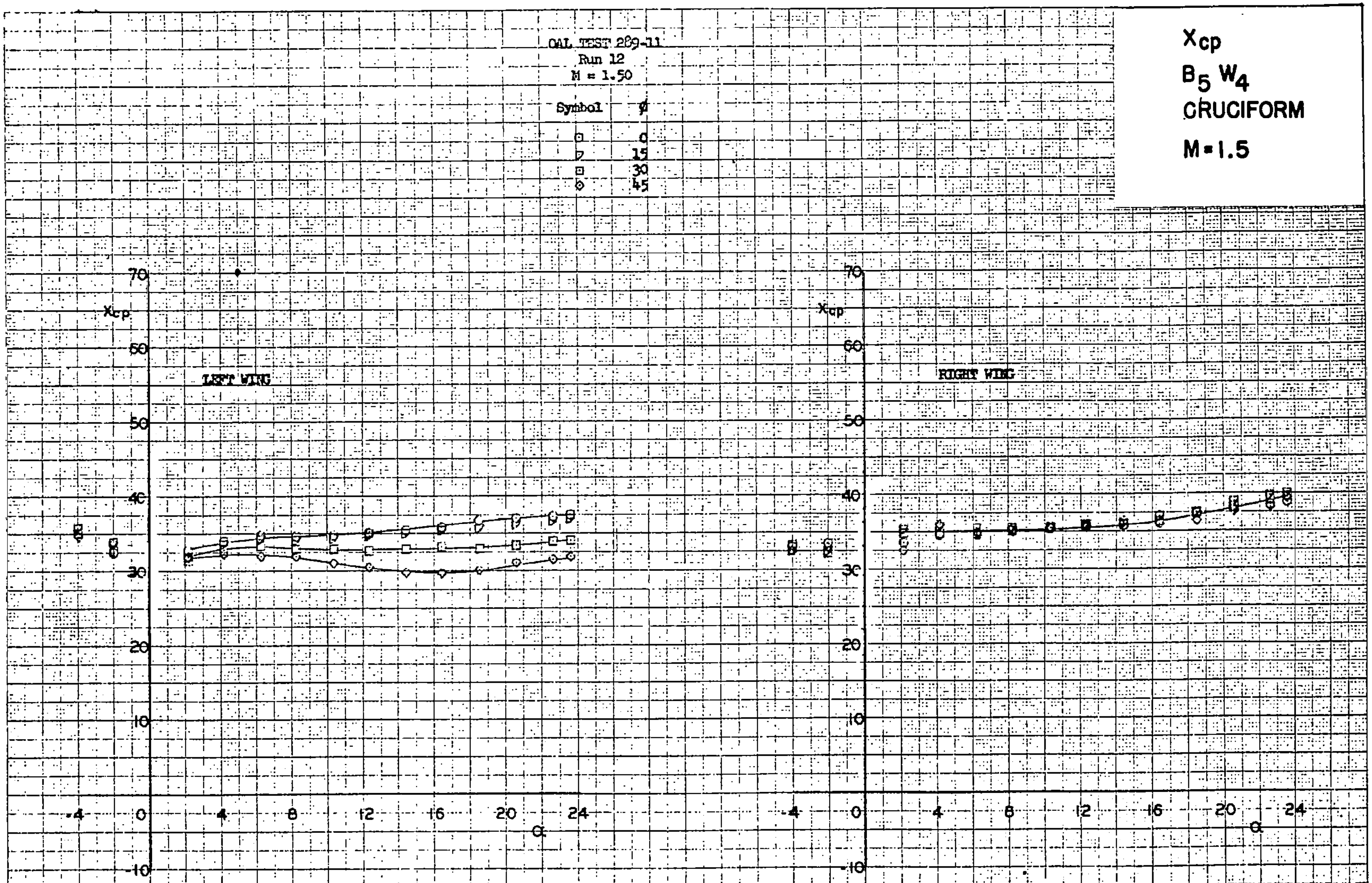


(b) W_4B_5, $i_4/i_4' = 0/0$
FIGURE 29 CONTINUED

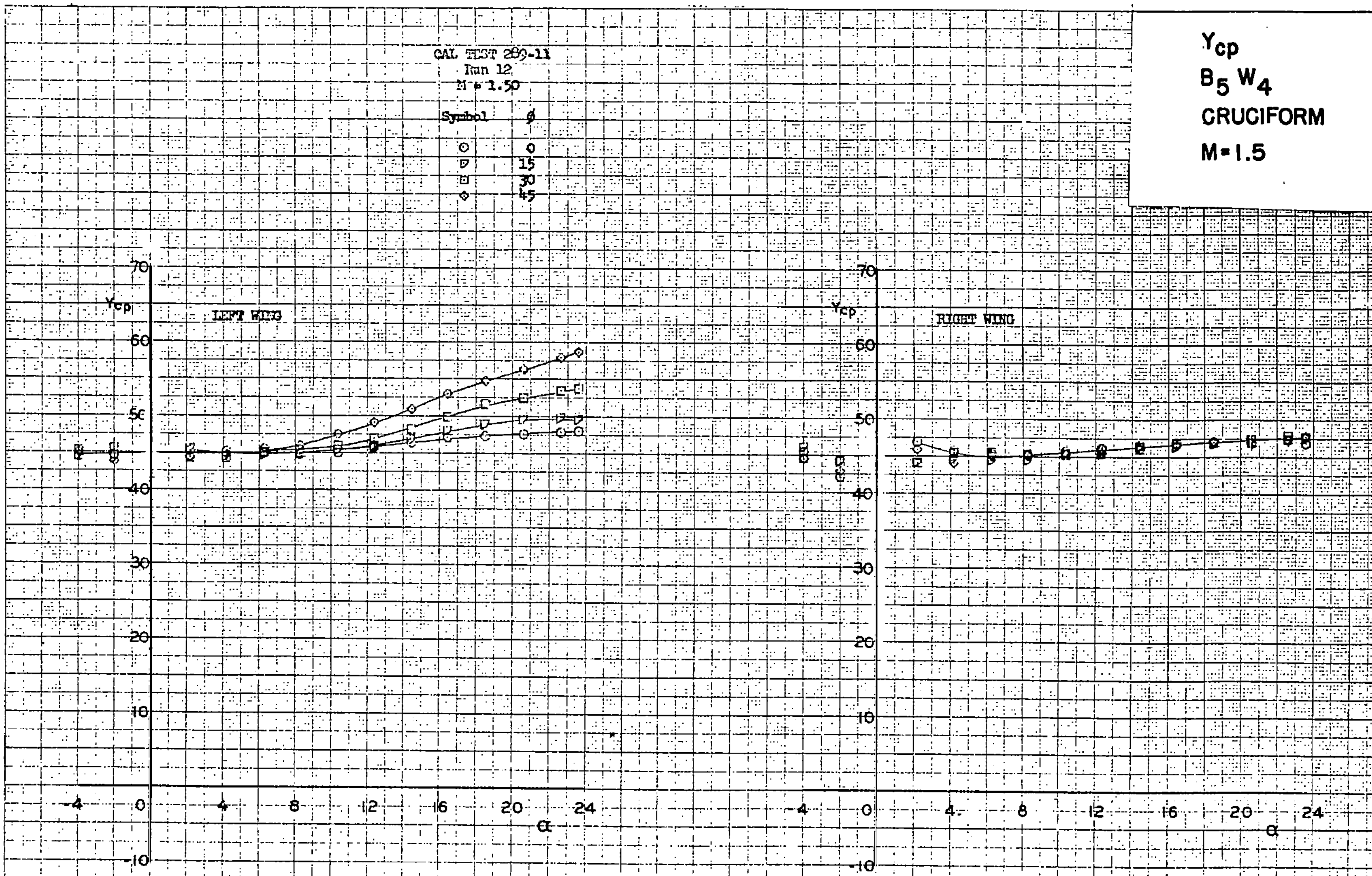


(a) C_{N_p} vs. α for W_4B_5, i_L/i_R = 0/0 (ϕ = 0 thru 45)

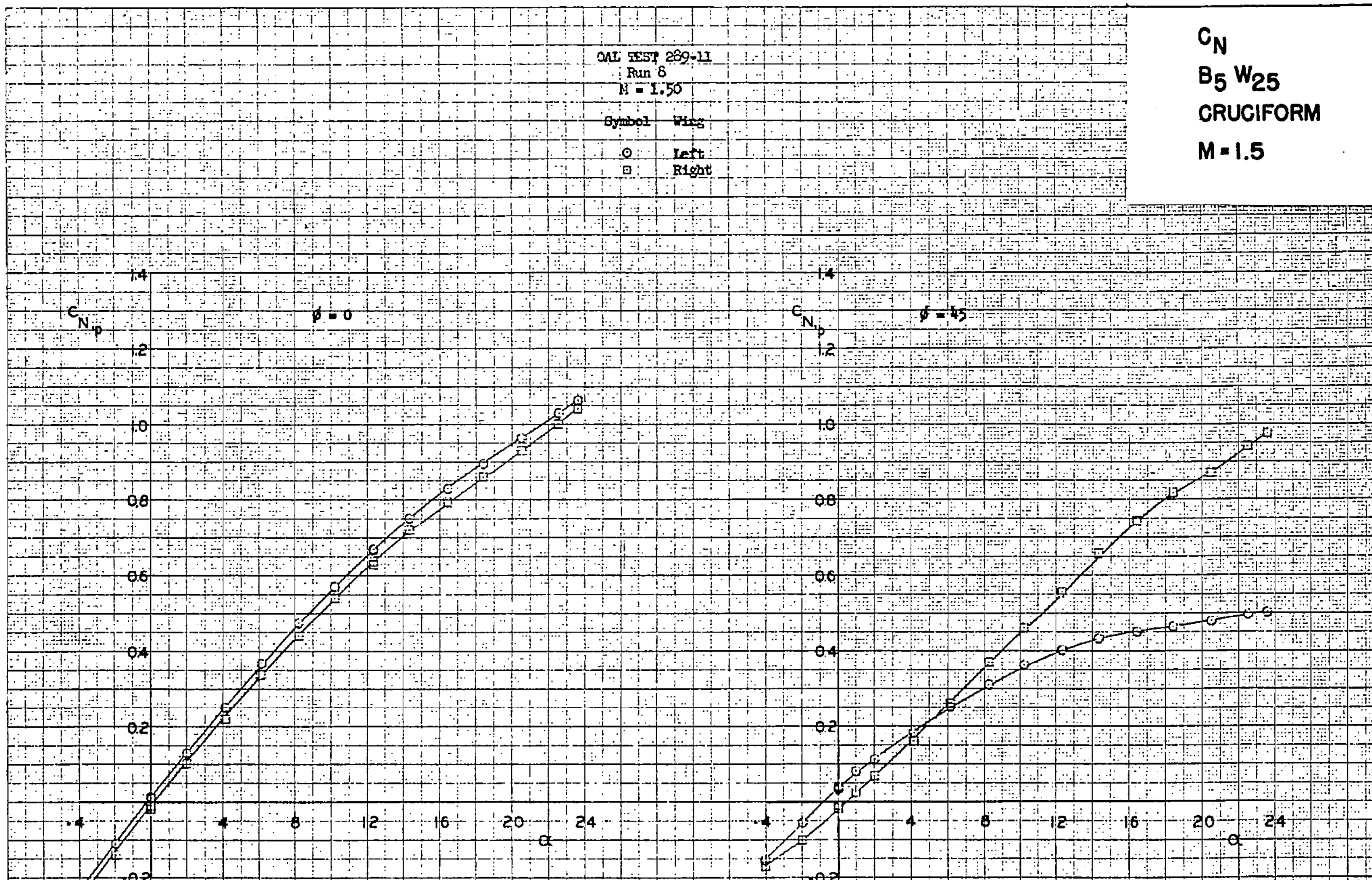
FIGURE 25 AERODYNAMIC CHARACTERISTICS OF THE LEFT AND RIGHT WING PANELS ON A CRUCIFORM WING-BODY CONFIGURATION (W_4B_5) WITH ZERO WING INCIDENCE AND WITH INCREASED FOREBODY LENGTH AT MACH NUMBER 1.50



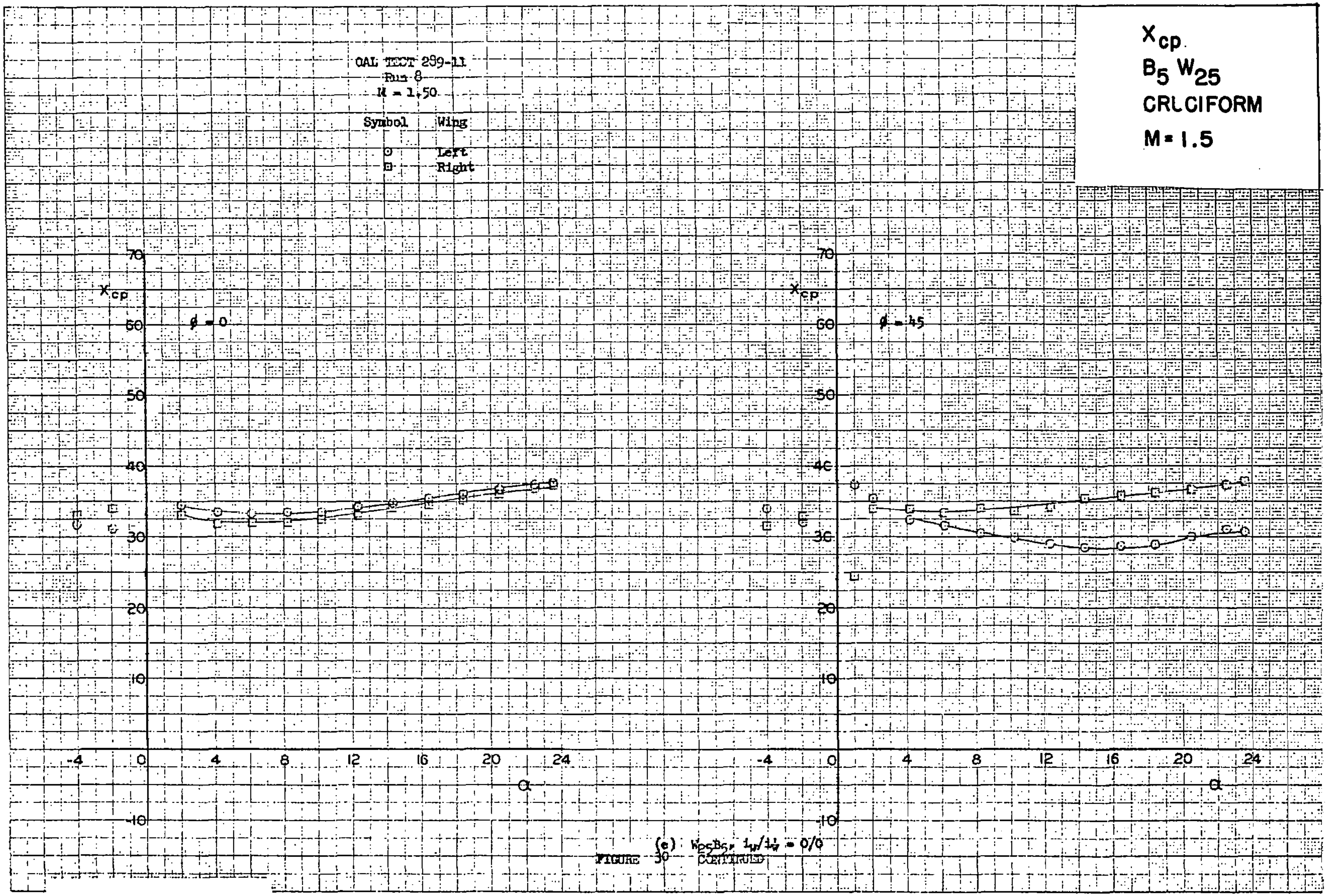
(i) X_{cp} vs. α for W_4B_5, i_w/i'_w = 0/0 (φ = 0 thru 45)
FIGURE 25 CONTINUED



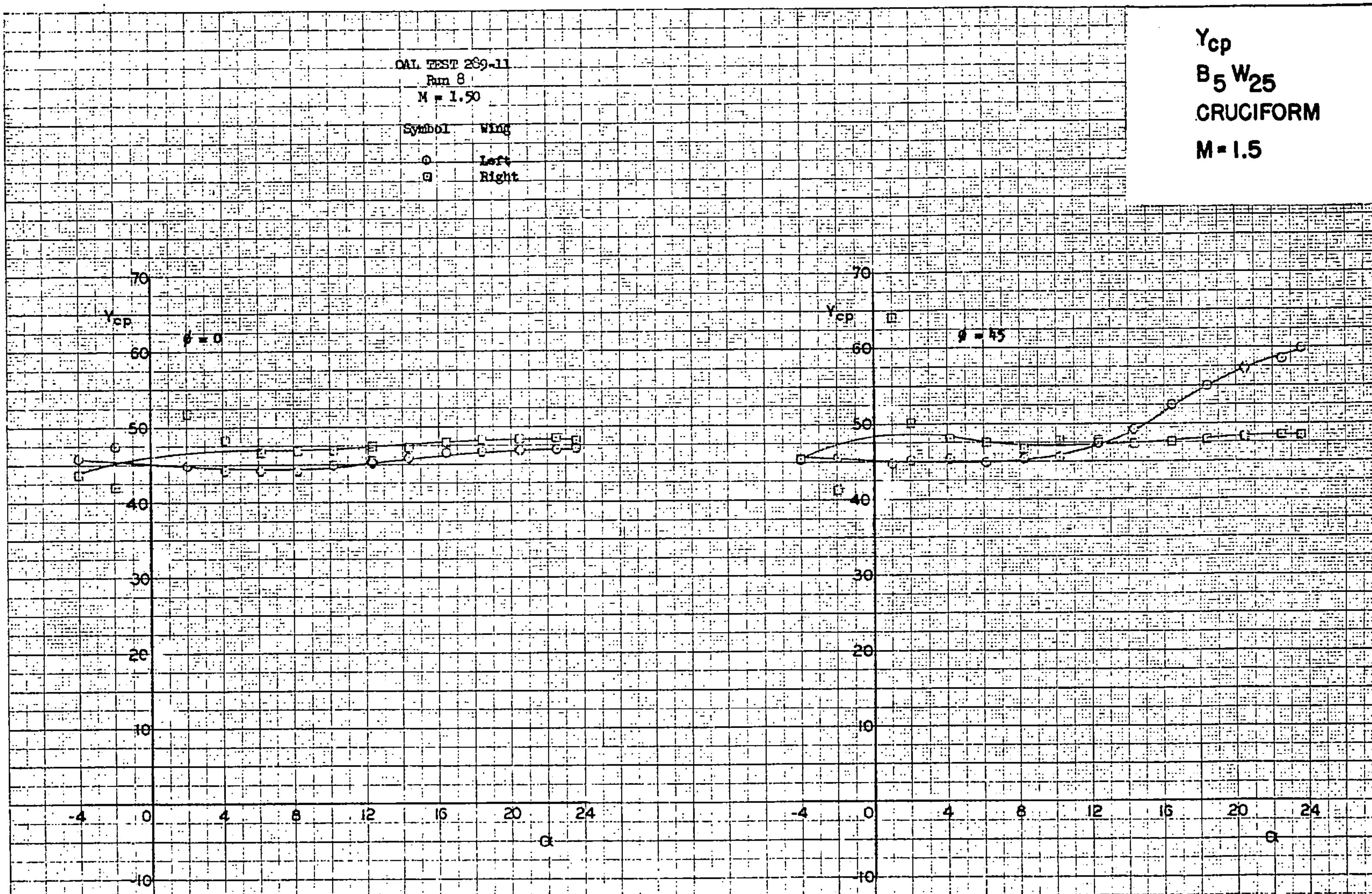
(g) Y_{cp} vs. α for W_4B_5, $i_w/i'_w = 0/0$ (ϕ = 0 thru 45)
FIGURE 25 CONTINUED



(e) $W_{25}B_5$, $i_w/i'_w = 0/0$
FIGURE 26 CONTINUED



(e) $W_{25}B_5$, $i_W/i'_W = 0/0$
FIGURE 30 CONTINUED



(a) $W_{25}B_5$, $i_w/i'_w = 0/0$
FIGURE 29 CONTINUED

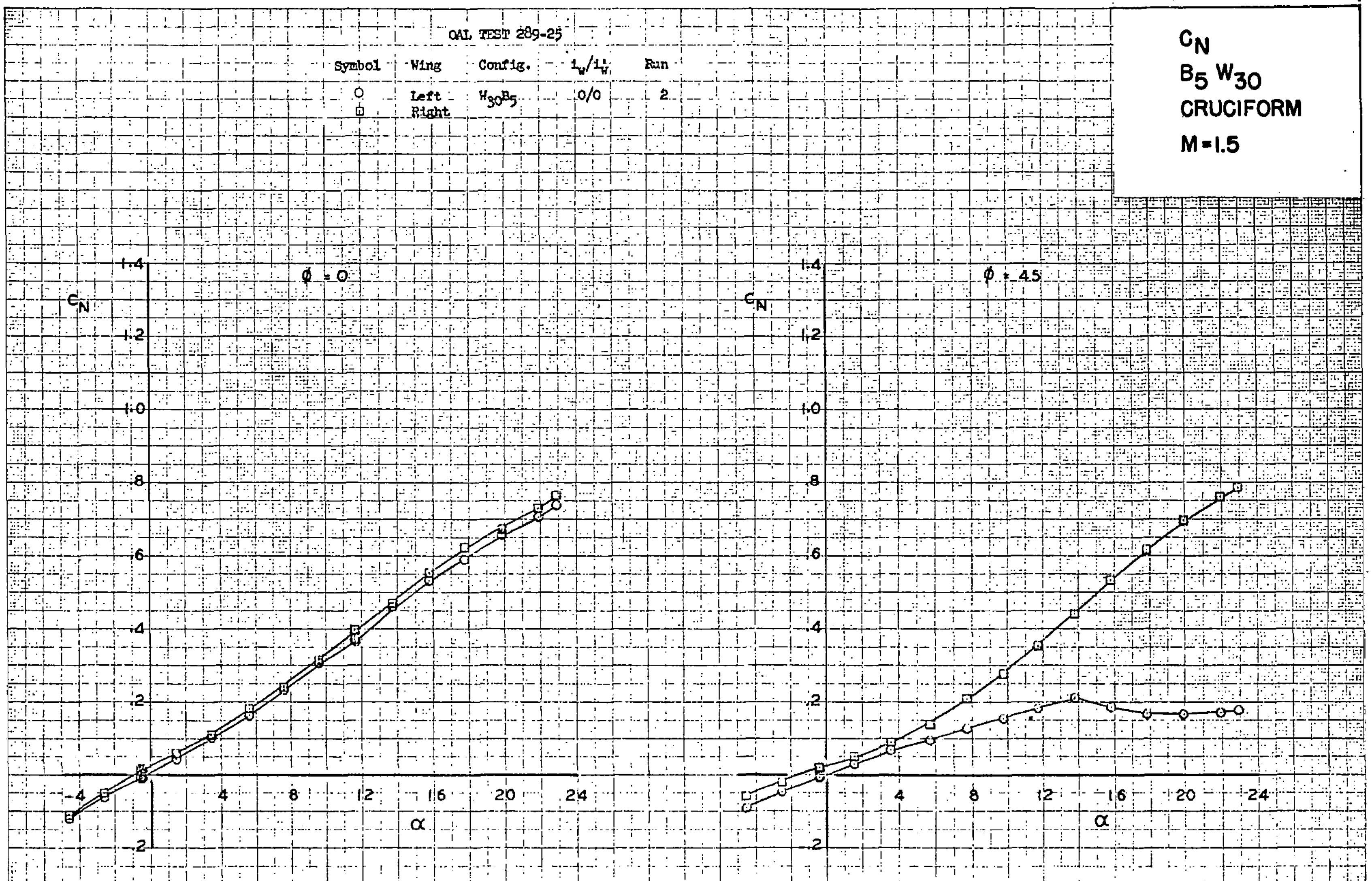


FIGURE 24 COMPARISON OF THE RIGHT AND LEFT WING PANEL NORMAL-FORCE COEFFICIENTS OF THE GMS MODEL IN THE PITCH AND COMBINED PLANES AT MACH NUMBER 1.50

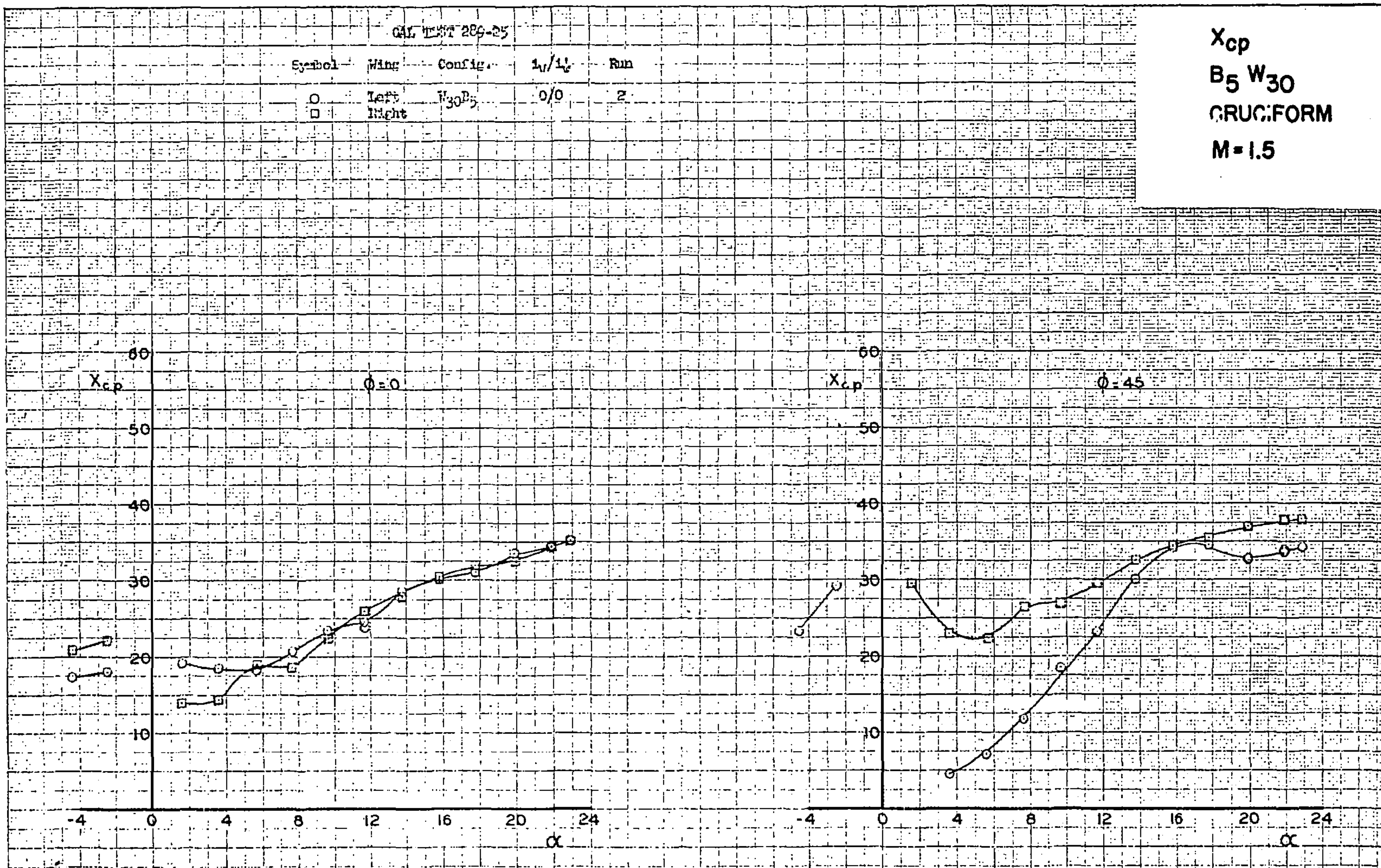


FIGURE 27 COMPARISON OF THE RIGHT AND LEFT WING PANEL CHORDWISE CENTER OF PRESSURE LOCATIONS OF THE GMS MODEL IN THE PITCH AND COMBINED PLANES AT MACH NUMBER 1.50

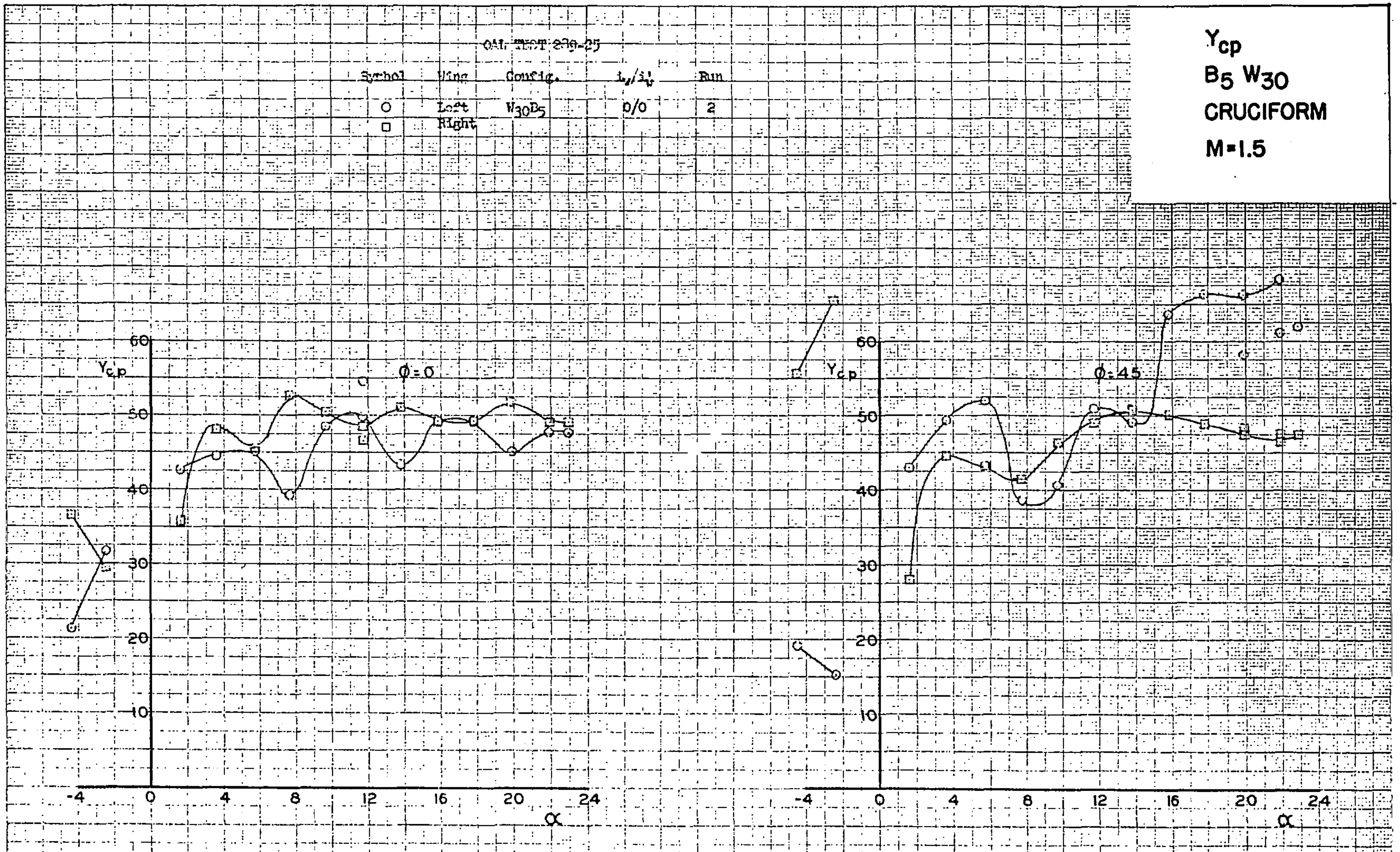


FIGURE 28 COMPARISON OF THE RIGHT AND LEFT WING PANEL SPANWISE CENTER OF PRESSURE LOCATIONS OF THE GMS MODEL IN THE PITCH AND COMBINED PLANES AT MACH NUMBER 1.50

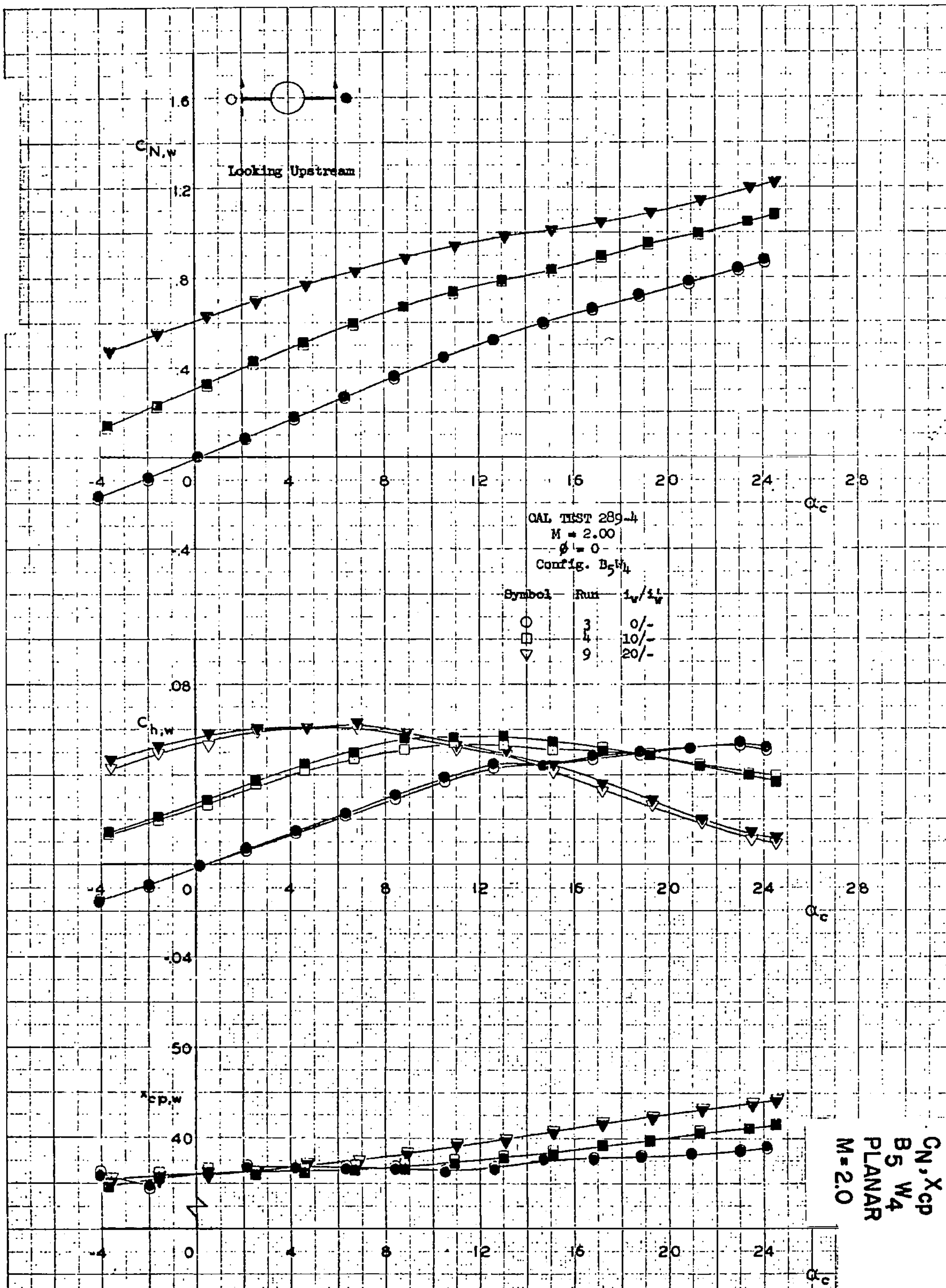
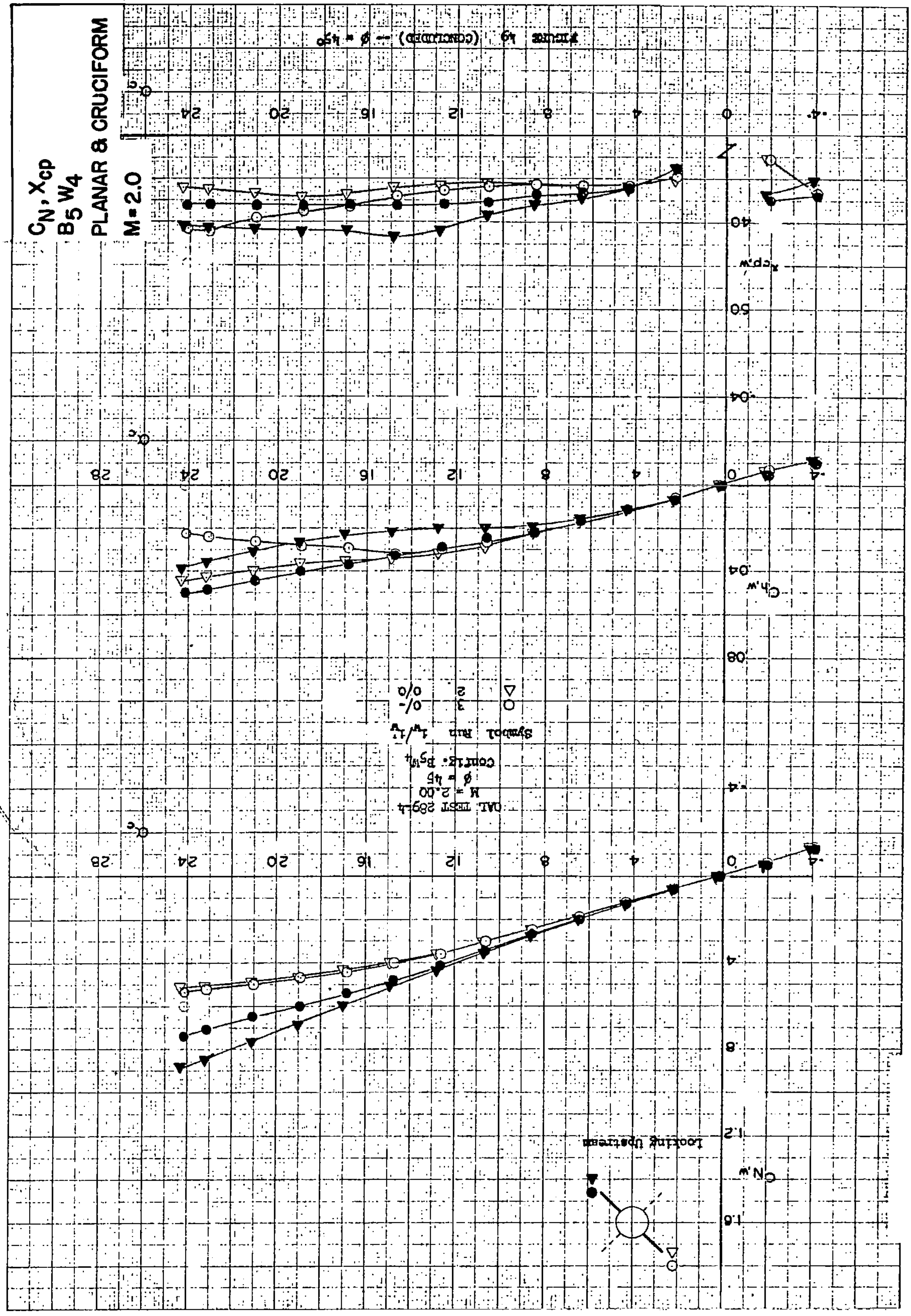


FIGURE 47 WING NORMAL-FORCE AND HINGE-MOMENT SHOWING THE EFFECT OF WING INCIDENCE -- CONFIGU
$\phi = 0°$


C_N, X_{cp}
$B_5 W_4$
PLANAR & CRUCIFORM
M = 2.0
FIGURE 49 (CONCLUDED) -- φ = 45°
OAL TEST 289-4
M = 2.00
φ = 45
Config: B_5W_4
Symbol Run l_w/l_t
Looking Upstream

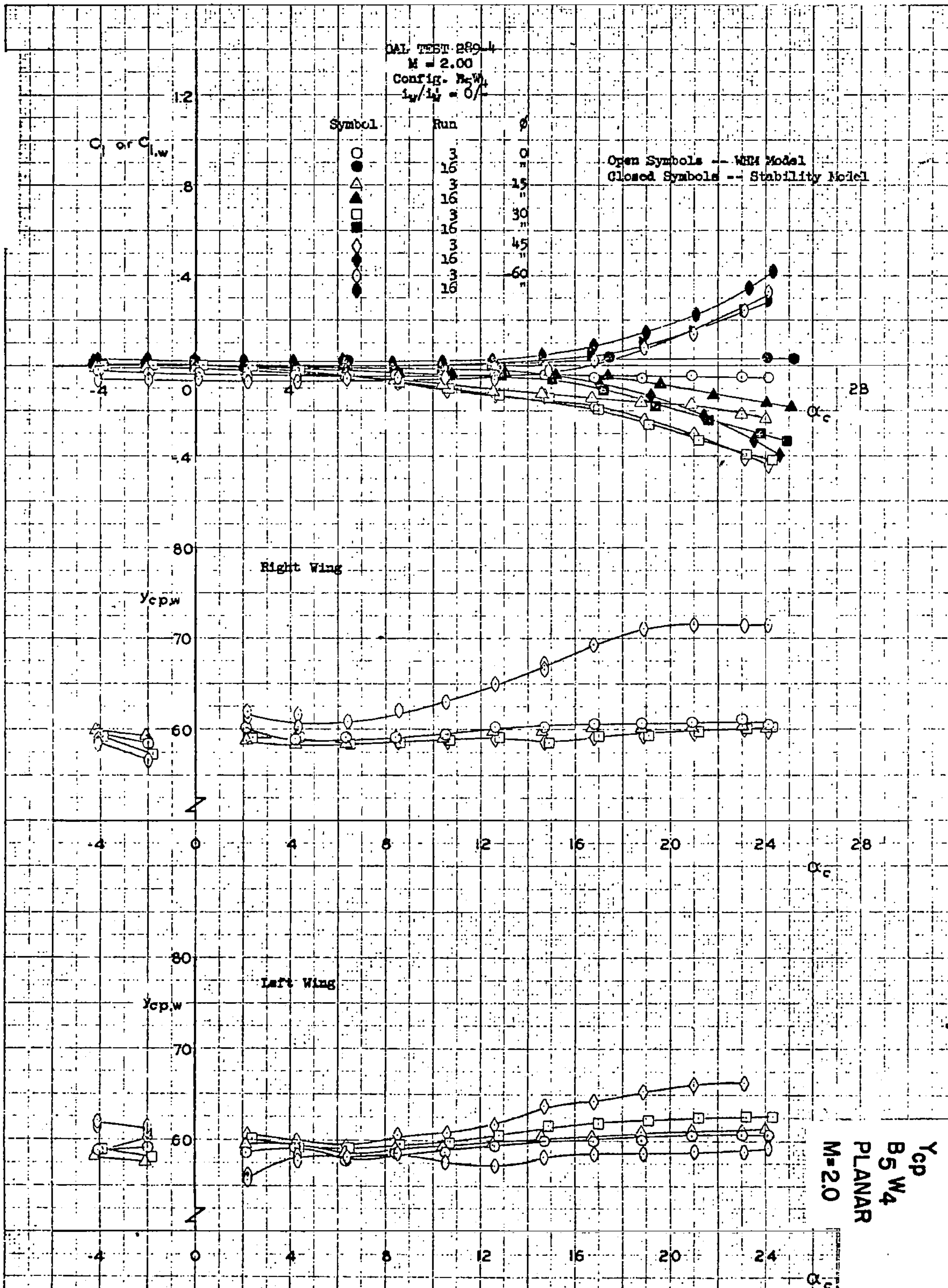


FIGURE 11. WING ROLLING-MOMENT AND SPANWISE CENTER OF PRESSURE OF A PLANAR-WING CONFIGURATION COMPARISON BETWEEN STABILITY AND WING HINGE-MOMENT MODEL DATA -- CONFIGURATION B_5W_4

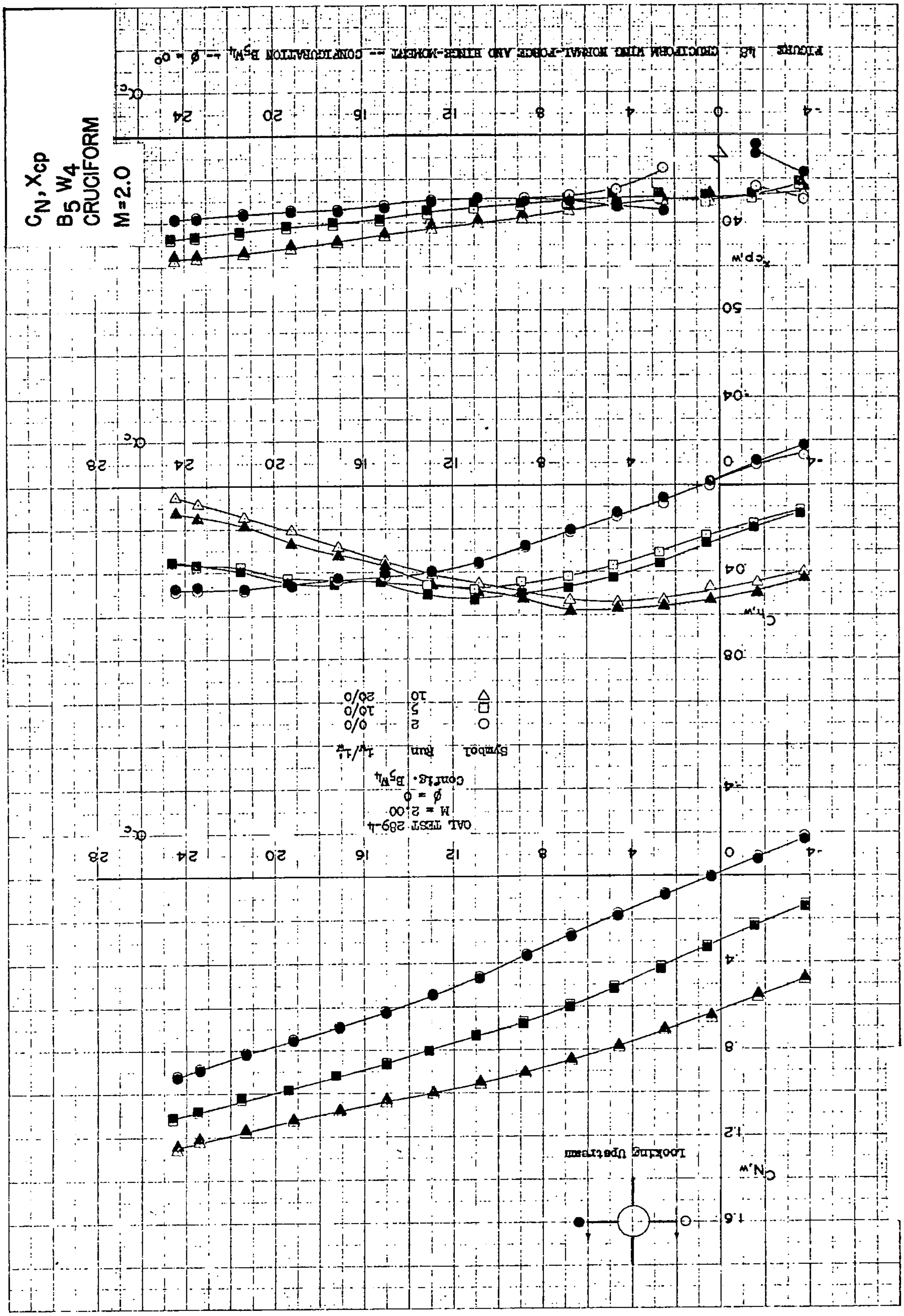
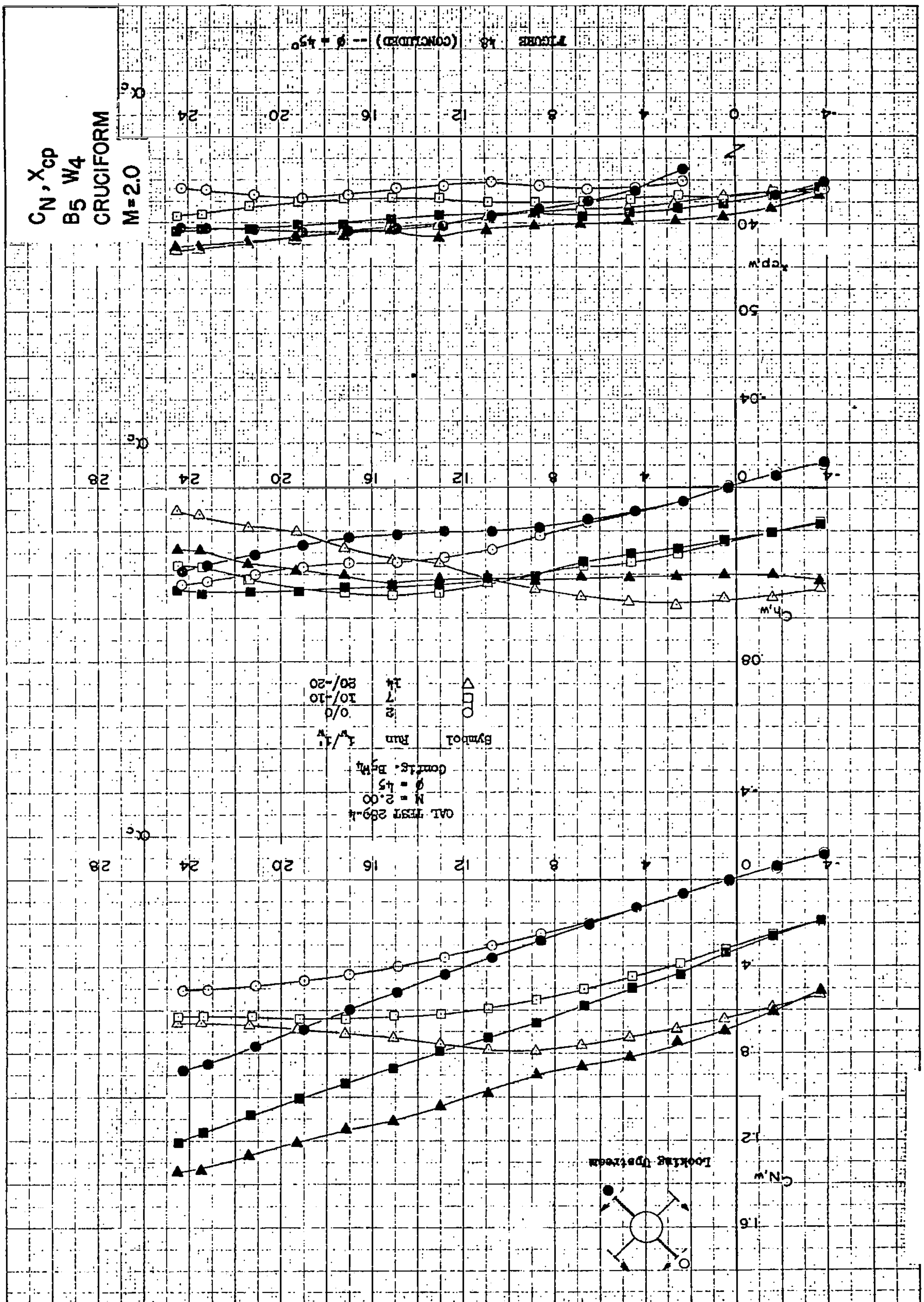


FIGURE 48 CRUCIFORM WING NORMAL-FORCE AND HINGE-MOMENT -- CONFIGURATION B_5W_4 -- ϕ = 0°



C_N, X_{cp}
B_5 W_4
CRUCIFORM
M=2.0
FIGURE 48 (CONCLUDED) -- $\phi = 45°$
CAL TEST 289-4
M = 2.00
ϕ = 45
Config. B_5W_4
Symbol Run i_w/i_v
2 0/0
7 10/-10
14 20/-20
Looking Upstream
$C_{N,w}$
$C_{h,w}$
$x_{cp,w}$
α_c

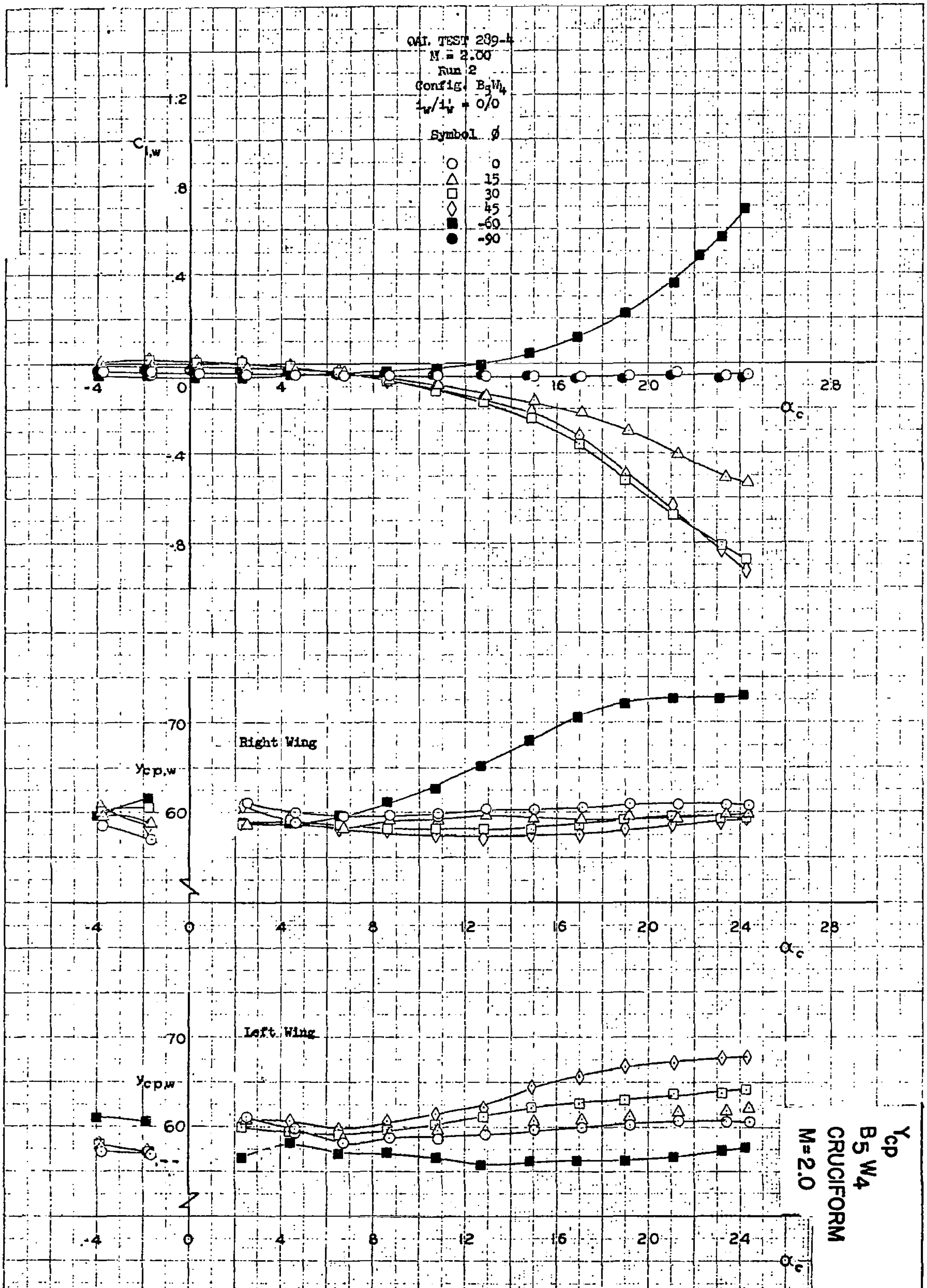
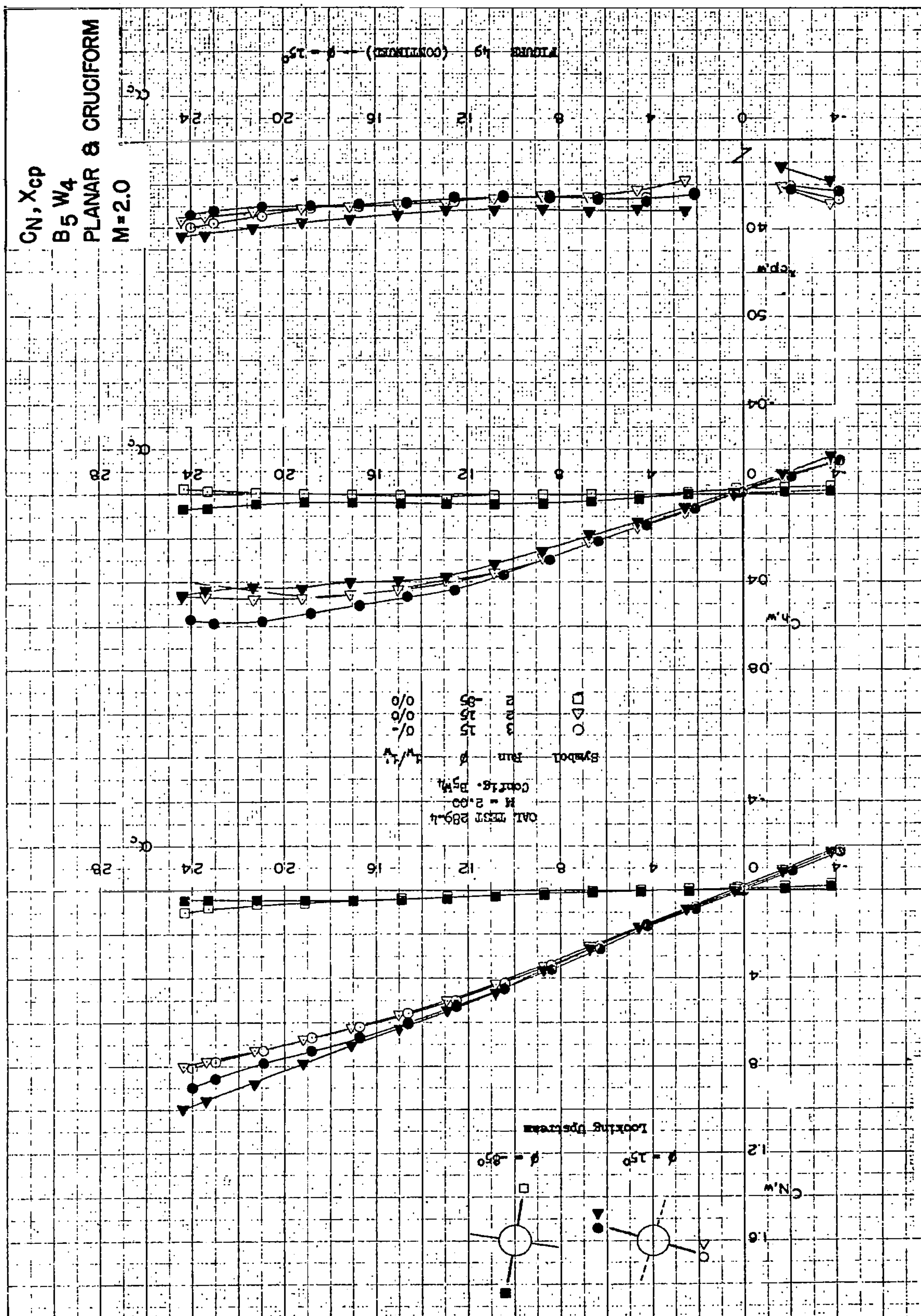
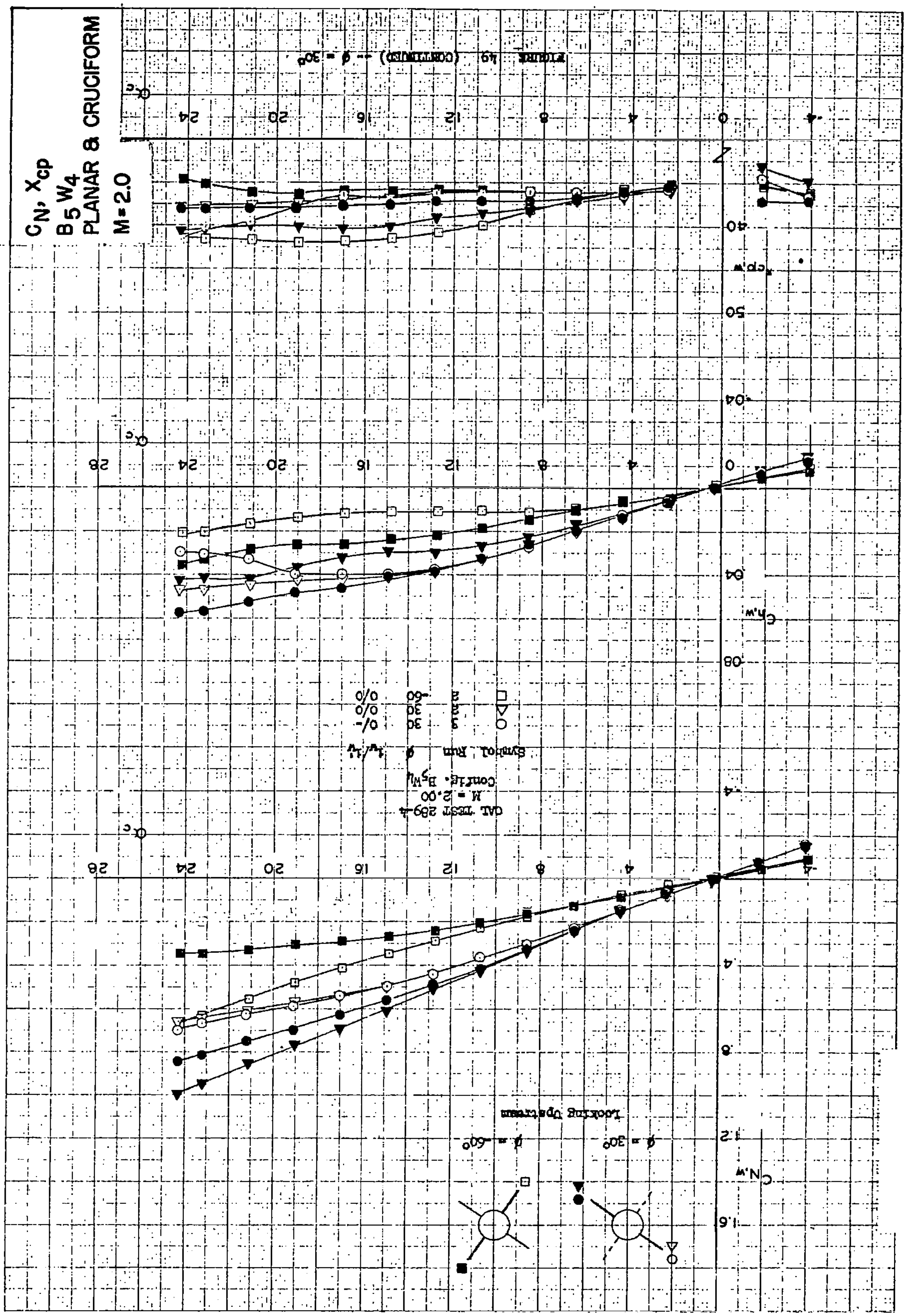


FIGURE 115 WING ROLLING MOMENT AND SPANWISE CENTER OF PRESSURE OF A CRUCIFORM-WING CONFIGURATION
CONFIGURATION B_5W_4



CN, Xcp
B5 W4
PLANAR & CRUCIFORM
M=2.0
FIGURE 49 (CONTINUED) — φ = 15°
OAL TEST 289-4
M = 2.00
Config. B5W4
Looking Upstream



CN, Xcp
B5 W4
PLANAR & CRUCIFORM
M = 2.0
FIGURE 49 (CONTINUED) -- φ = 30°
CAL TEST 289-4
M = 2.00
Config. B5W4
Symbol Run φ iw/it
Looking Upstream
φ = 30°
φ = 60°

C_N
$B_5 W_{25}$
CRUCIFORM
M = 2.0

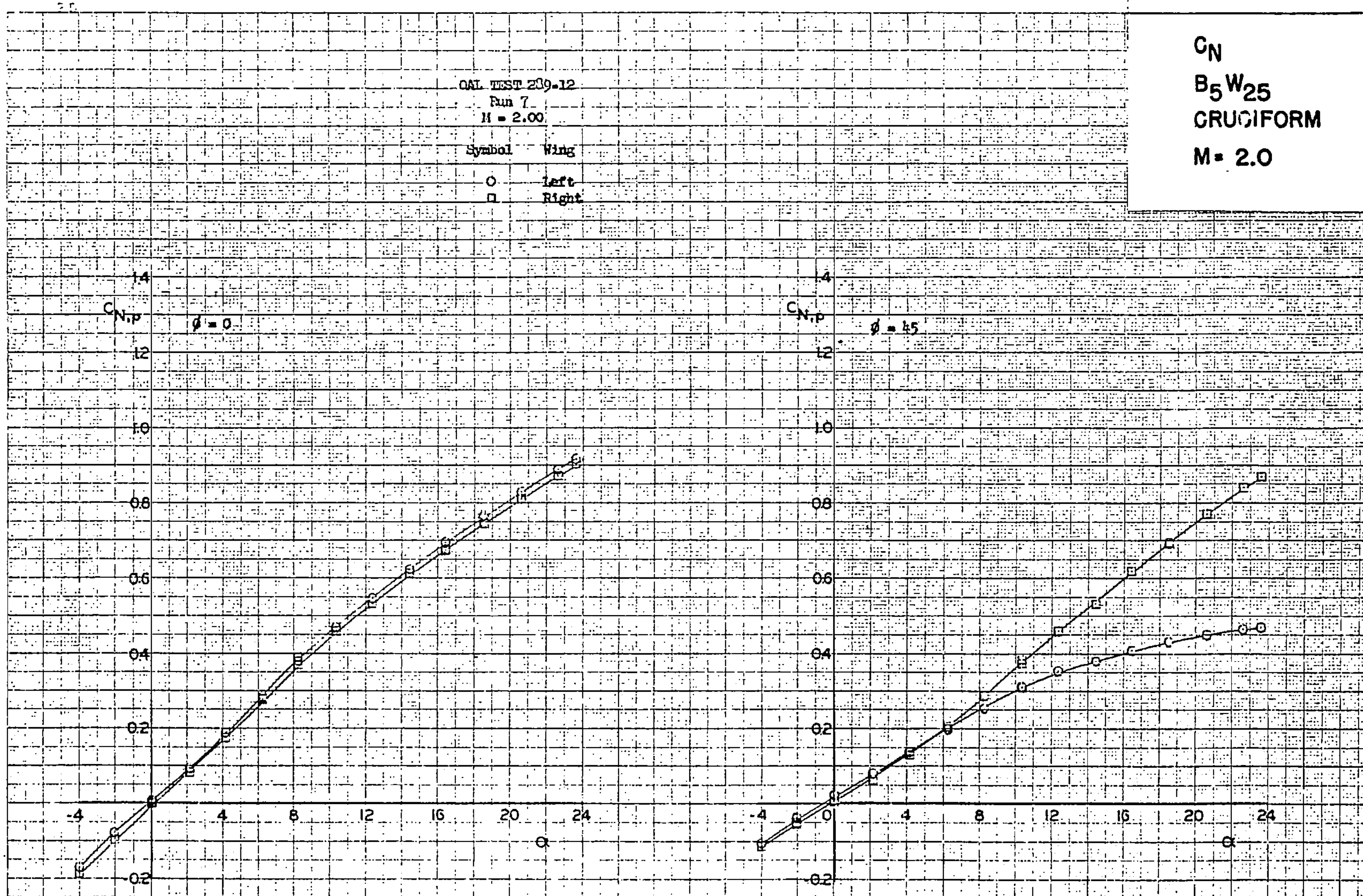


FIGURE 35 (e) $W_{25}B_5$, i_v/i_v = 0/0 CONTINUED

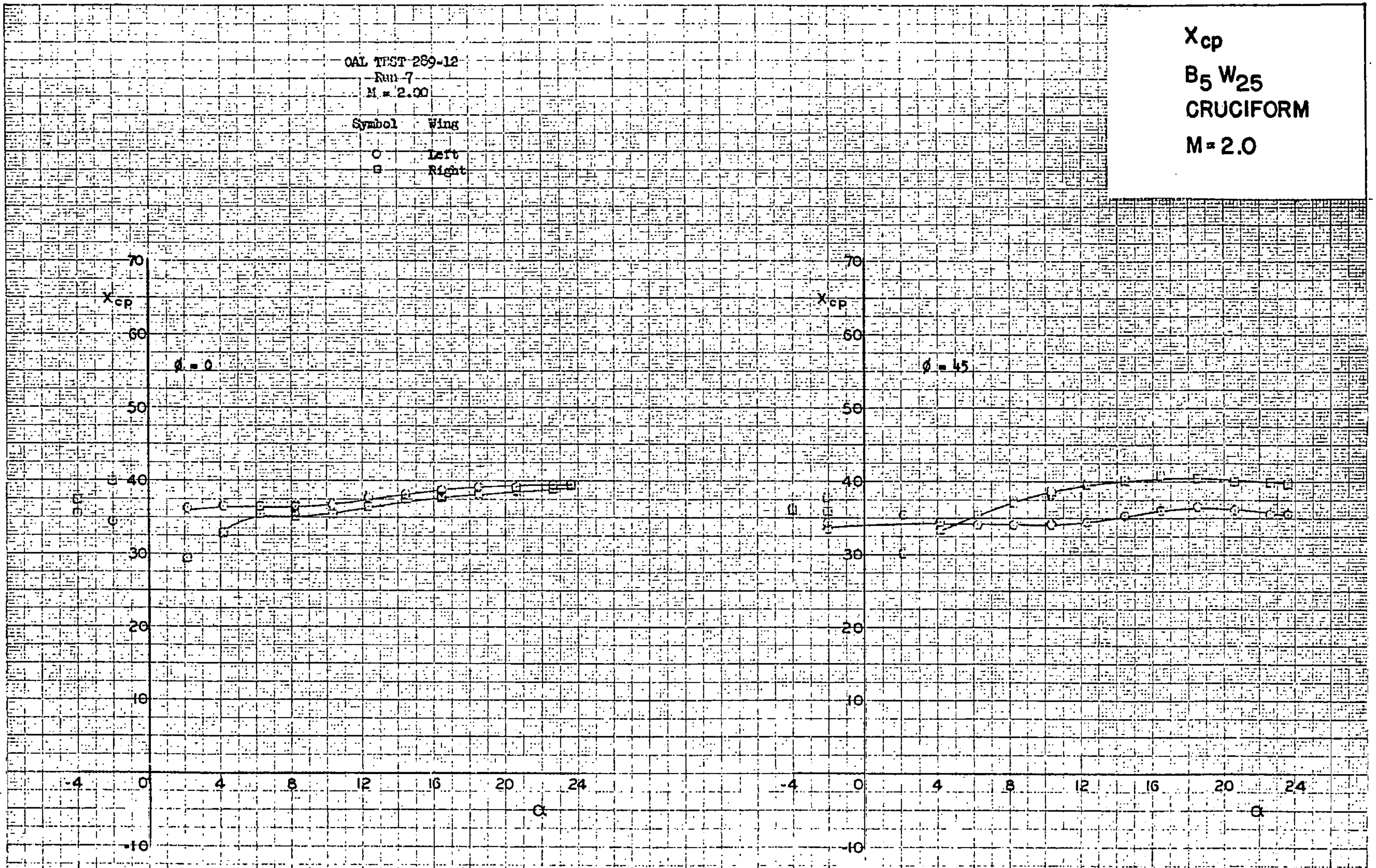
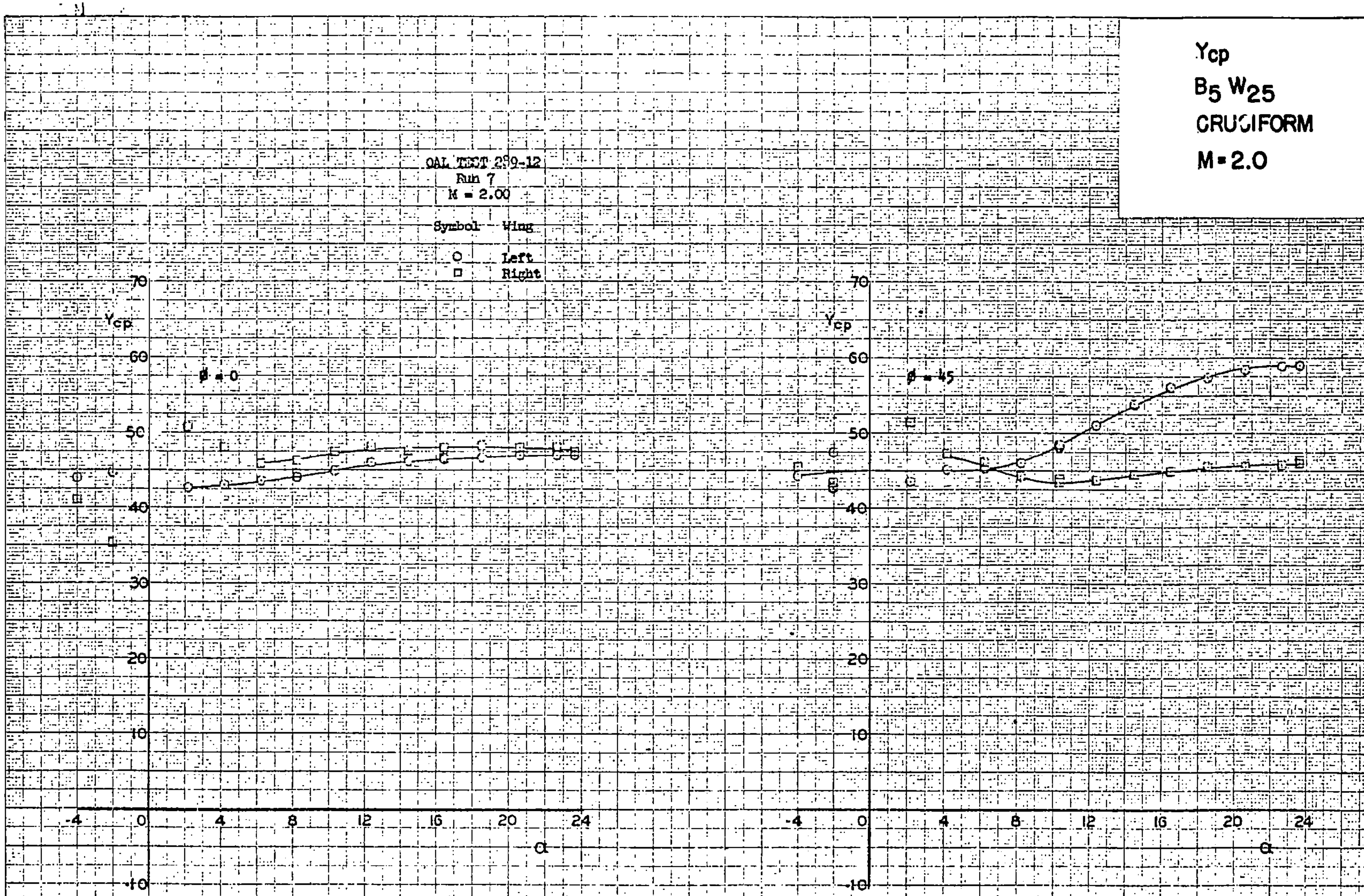


FIGURE 39 (c) $V_{25}B_5$, i_w/i_v = 0/0 CONTINUED



(c) $W_{25}B_5$, $l_W/l'_W = 0/0$

FIGURE 38 CONTINUED

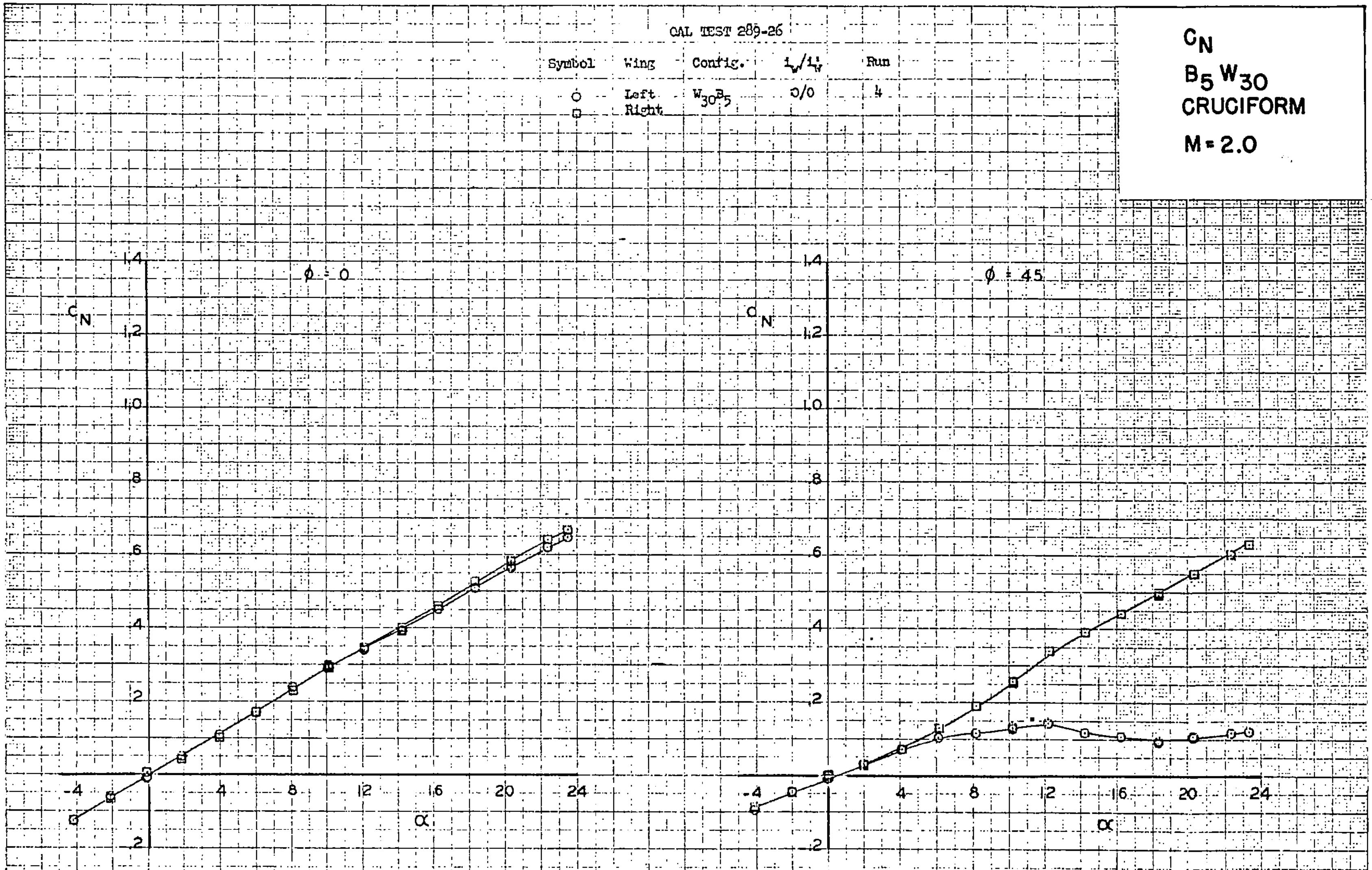


FIGURE 64 COMPARISON OF THE RIGHT AND LEFT WING PANEL NORMAL-FORCE COEFFICIENTS OF THE GMS MODEL IN THE PITCH AND COMBINED PLANES AT MACH NUMBER 2.00

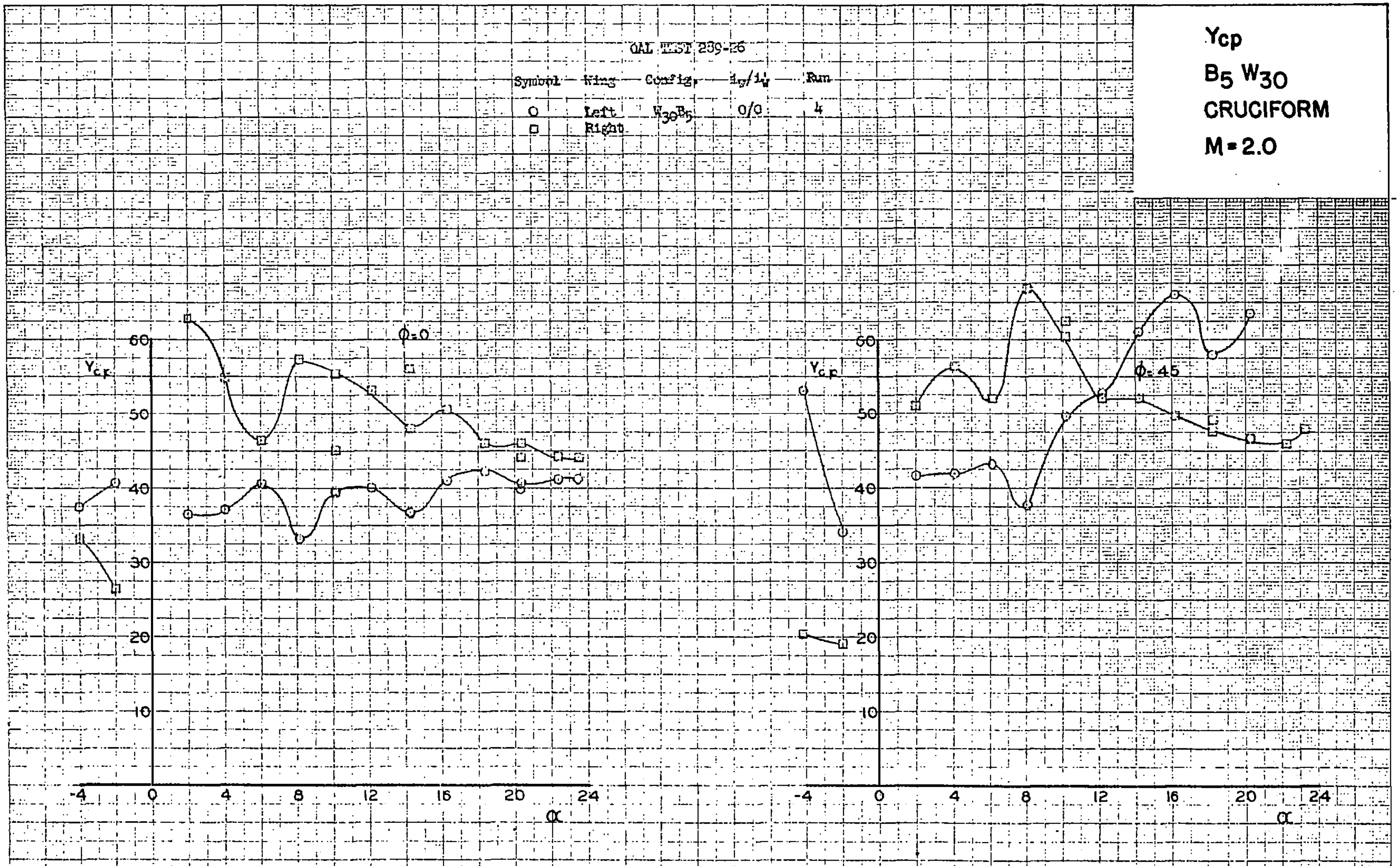


FIGURE 68 COMPARISON OF THE RIGHT AND LEFT WING PANEL SPANWISE CENTER OF PRESSURE LOCATIONS OF THE GMS MODEL IN THE PITCH AND COMBINED PLANES AT MACH NUMBER 2.00

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16. Abstract

The Bumblebee Program, initiated in 1945 by the U.S. Navy Bureau of Ordinance, was designed to provide a supersonic-guided missile. The Aerodynamic Program included a fundamental research effort in supersonic aerodynamics as well as a design task in developing both vehicles and prototypes of tactical missiles.

A series of four reports were prepared in order to facilitate dissemination of a large amount of fundamental aerodynamic missile data, which has been stored for a number of years at the Applied Physics Laboratory.

This report provides individual wing panel aerodynamic characteristics (specifically, normal force coefficient and center-of-pressure location) for rectangular wings of three different aspect ratios (0.25, 0.75, and 1.00 each panel).

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